Indian Institute of Technology Madras
Presents

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Aerospace Propulsion
Solid Rockets - Propellants

Lecture - 24

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In the last class we had looked at how nozzle performances and we had initially made a simple one-dimensional steady flow approximation and we also looked at what are the shortcomings of it till the last class we did not bother ourselves about what kind of rocket engine are we talking about that is liquid solid or hybrid okay from this class on let us look at solid propellants for the first few classes and then we will go to liquids and then do hybrids take so solid propellant rocket.

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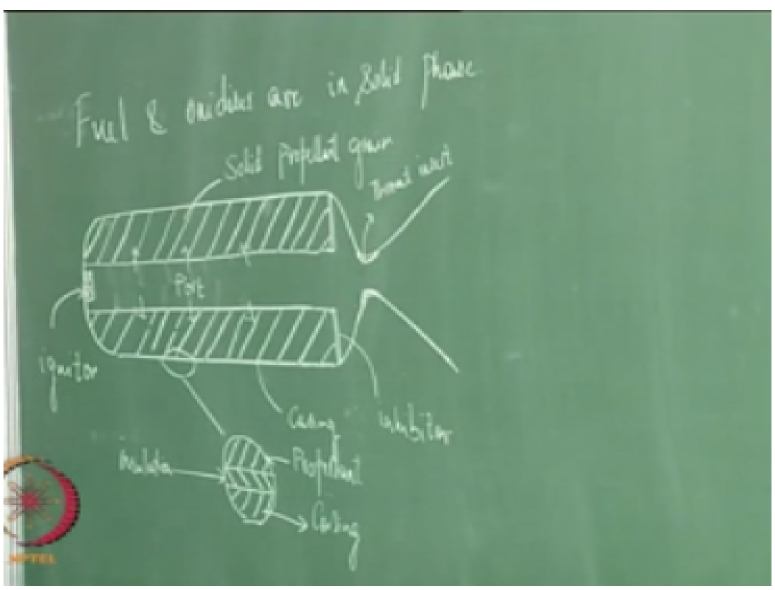

In this both the fuel and oxidizer are in solid phase and that is why this name that solid propellant rocket as I had said earlier this puts a restriction on the kind of chemicals that we can use for solids and liquor for the fuel and oxidizer and therefore the performance of solid propellants are going to be slightly inferior to those of liquids okay, now let us look at how a solid rocket motor looks like and what are the parts in it how do they function, now this is the typical sketch of a solid propellant motor you will have something known as the propellant grain it is usually referred to as grain here.

Then you will have something known as a port where in the combustion takes place and the propellant burns in this direction, now you also have an igniter to initiate the combustion okay and then once the igniter is supplied with the electrical input this burns and causes the ignition of the propellant once the propellant burst starts to burn then gases get released from these surfaces and because we have a throat here right what happens is these gases tend to build up the pressure inside the port okay and once the pressure is above a certain value compared.

To the exit pressure the flow will be choked and we know that for at rope flow we know that mass flow rate is given by.

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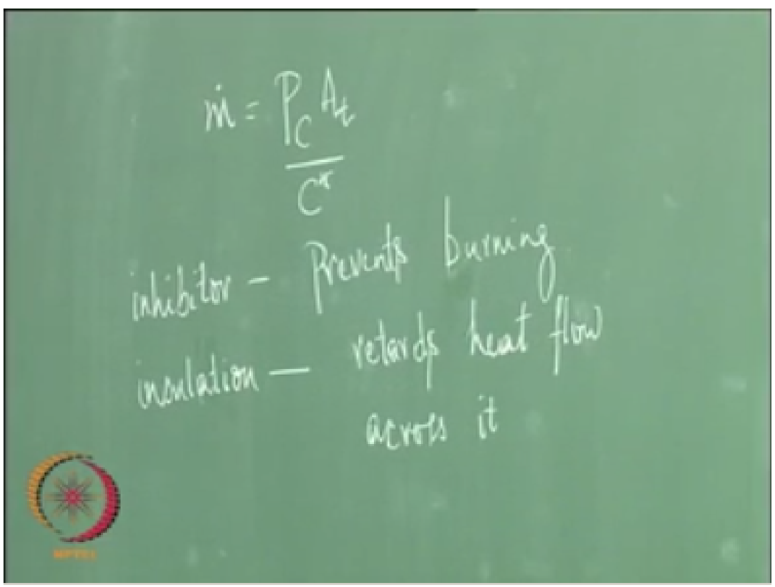

m. is equal to write or in other words I can also get the chamber pressure from this equation depending on what is the mass flow rate through the nozzle, so in essence this is a self pressurized system you do not need any pressurization system to take it to high pressures okay, so there is a self pressurization pressurized system and it operates at high pressures of in excess of 70 bar or something like that and then once the propellant starts burning the gases are produced and there will be a stage when the mass that is produced by the burning of the propellant is equal to the mass that is flowing through the throat that will indicate the steady operating conditions okay.

Now if you look at a small section here close to the casing it will look like this you will have a propellant grain and then a layer of insulation okay, so there is a layer of insulation between the casing and the propellant okay, now let us look at each of them in a little more detail if you look this has also something known as a inhibitor, now an inhibitor this prevents combustion from taking place in this direction normal to the surface so there will be no combustion in this direction okay.

So this prevents combustion from taking place in this direction because this propellant is also exposed to hot gases, so this could burn okay and whenever you do not want a surface to regress which is exposed you can apply an inhibitor and that will prevent combustion from taking place in that eyes now there is also something known as an insulation here insulation all of you must have known this that does not prevent or prevents heat from retard Crossett then there is something known as a throat insert this is for the thermal protection of the throat cross section.

We will come to that a little later as to why we need this in terms of cooling requirement and other things will come to that a little later then port is the region where the combustion takes place and usually an igniter is again a solid propellant which has slightly higher metal content okay and upon providing it the electrical energy, it starts to burn and throws out this particulate matter and gases and if the particle matter gets embedded here then this is hot surface and then this ignites the propellant locally.

And then the flame spreads from the head into the nozzle and now if you look at how the pressure time curve for this propellant will look like as I said this is a self pressurized system yeah this will be the pressure versus time plot for this kind of solid rocket motor, we will come to why it is increasing after it comes down to a certain value a little later now there are two kinds of solid propellants that have been predominantly used one is known as homogeneous or double-bass solid propellant.

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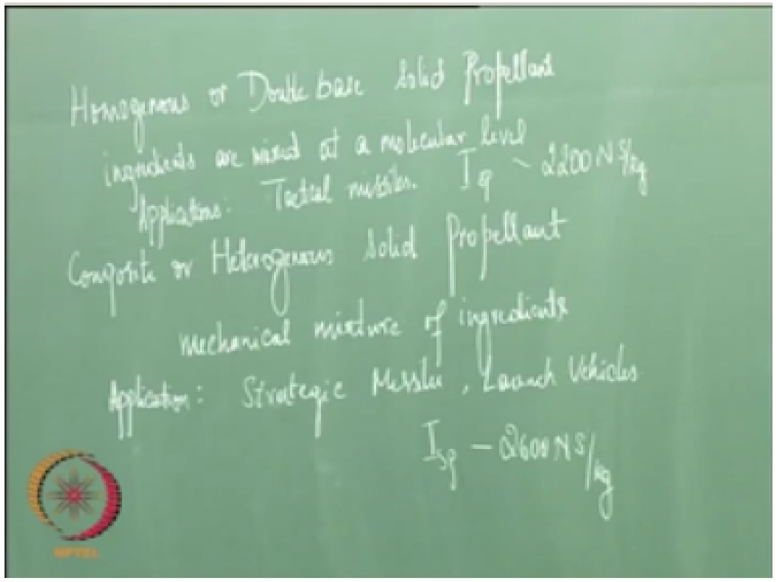

And the other one is composite or heterogeneous solid propellant now homogeneous solid propellant in this case both the fuel and oxidizer are mixed at a molecular level, and if you take a small section of this propellant you will not be able to distinguish between a fuel and an oxidizer so in this case ingredients are molecular level whereas in a composite propellant, if you cut a small portion of the propellant you will be able to see fuel and oxidizer in this case the oxidizer that is typically used is a particulate matter and therefore you will be able to distinguish between fuel and oxidizer.

So in this case ingredients this is a mechanical mixture of ingredients now why do we have two different kind of propellants they are there to address two different kind of applications, if you look at composite propellants usually they have a better performance that is specific impulse higher specific impulse and they are preferred to be used in strategic missiles and in launch vehicles okay whereas, if you look at homogeneous propellants they are typically used in tactical missiles.

If you look at the composition of the composite propellant this will have a fraction of metal loading in it because of which, if you have a metal loading then the exhaust will have a very strong heat signature and therefore you do not find them being used in tactical missiles tactical missiles are short-range missiles and they have typically battlefield missiles, so if you have if you use this propellant in tactical missiles.

What will happen is you will very easily give away your location to the enemy right because it has a very strong signal heat signature and the enemy can find out where the missile was fired from and hit back the position, so you do not want that and therefore in tactical missiles you will typically use homogeneous propellant and you we will see that you can also kind of reduce the visible smoke there are some things known as smoke suppressants if you add them the smoke that is coming out of the propellant will also be very small okay.

So that is why homogeneous propellant although they have a slightly inferior specific impulse compared to composite propellants they are still being used in tactical missiles typically the ISP of this would be somewhere between 2200 whereas this can go up to 2,000 now let us look at these two propellants in a little more detail firstly let us take up the homogenous problem.

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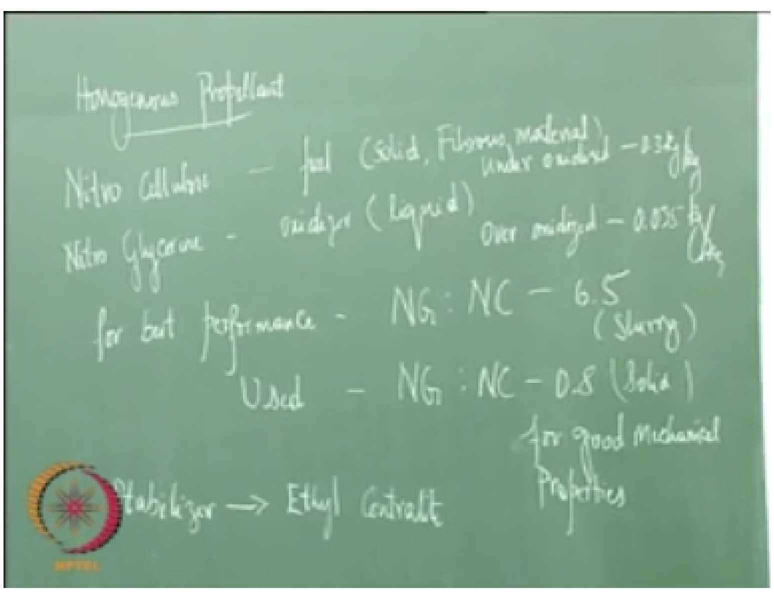

Now this has nitrocellulose and nitroglycerin in almost equal percentages and that is why it is also known as a double base propellant okay, because it has in essence two bases so here nitrocellulose this is the fuel and it is a solid and has is a fibrous material nitroglycerin is the oxidizer and is a liquid okay, now this is this has under it this is under oxidized by something like 0.3kg/kg and this is over oxidized okay, both of them have fill and oxidizer in them this is under oxidize there is over oxidized.

So therefore this turns out to be the oxidizer and this turns out to be the field, now if you want to have a very good performance that is if you want to have a very good ISP remember we talked about this earlier also any propellant is always fuel rich primarily because we want the C star to be highest not just temperature to be highest temperature will be highest at a slightly fuel rich condition right from this to isometric but we go to an extremely fuel rich case primarily because we want the molecular weight also to be lower.

Now for best performance a combination of this the N_C or the ng N_C ratio would be something like 6.5 but what is use this oh 0.8 any idea why such a glaring difference between what is used in what is going to give us best performance, sorry no if you look at what is written here this is a solid and this is a liquid like and when you mix them in this proportion 6.5 it will become a slurry and will no longer be a solid propellant and if you want it to be a solid propellant with good mechanical properties you need to go in for this kind of ratio.

Why do we need the good mechanical properties for a propellant or casting yes then okay in some sense all of it and, if you notice in this figure here you have a propellant that is either that is has to go with the casing now the propellant typically will be a very large mass in a rocket motor typically of the order of 80% will be propellant, so if you have this and if you have very large accelerations right yeah typically in tactical missiles the accelerations can go to 10 G, if you have that then the propellant will extrude itself out through the nozzle if it does not have very good mechanical properties.

Or if it is very brittle it will break up and then in that will also give rise to problems, so you would want a very good set of mechanical properties with percentage elongation around 30% right and yield stress and tensile stress to be high also therefore it has to withstand not only G loads and also, if you notice the pressurization here it is a very fast pasteurization right, so that is also again a one more this is like an impact load because this is a very short time in which this load comes on to the drop line.

So you need to have good mechanical properties in order to withstand all these conditions and also during transport and other things the propellant should not break up and that would lead price will give rise to catastrophic failures a little later when it is used, so you will want all that therefore you have to have good mechanical properties, now in addition to NCAA ng you also have something known as a stabilizer typically these cells stabilizer used is ethyl centralite why do we need a stabilizer if you look at the nitrocellulose and nitroglycerin they are very reactive compounds now you are going to have them together.

In the same chamber and you would not also want reactions to take place okay, so therefore you add these stabilizers in small quantities so as to prevent reactions from taking place, so this is in order to prevents low reaction and degradation with time, if you are looking at a solid propellant for a military application it needs to have a certain shelf-life okay, typically of the order of a few years 10 to 15 years is its shelf-life once you make it you can keep it and store it for 10 to 15 years if you want that if you have this kind of reactive compounds.

You need to ensure that over the period of time there is very little degradation you cannot prevent it, but you can minimize it and that is why these stabilizers are added, now in addition to these stabilizers we also add certain burn rate modifiers.

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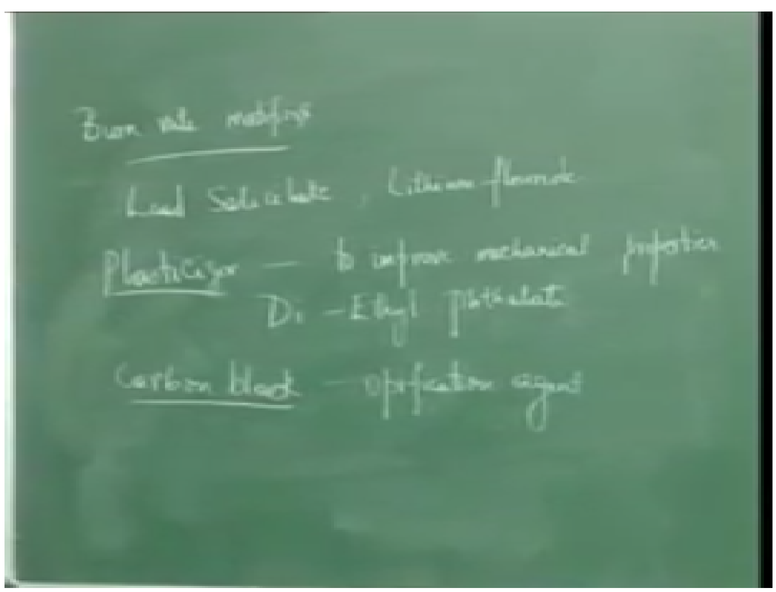

Now burn rate modifiers are chemicals that are added in very small quantities they are like catalyst, if you look at the rocket literature there you will also find rockets I mean the reference to these chemicals as both catalysts and burn rate modifiers a catalyst is a substance that does not take part in the reaction, but it is the reaction here if you are looking at a rocket motor everything burns up so the term catalyst probably is not very appropriate but it is still used interchangeably the typical burn rate modifiers for homogeneous propellants are late solicited like a little eight.

And then the theme flow right okay these are also used in order to get the required burn rate that we desire from the propellant is this going to be good enough to make this kind of solid propellant homogenous or do we act need to have something else as I said it needs very good mechanical properties, so there is something known as plasticizer that is added to improve the mechanical properties so the typical plasticizer used is diethyl phthalate sorry okay and in addition to this there is something that is used.

In these propellants that is carbon black now carbon black is nothing but carbon that is used there is also known as a notification agent, if you mix all the other things except the carbon black the propellant will be translucent in nature, okay if it is translucent it can absorb radiation and it have absorbs radiation and somewhere inside the material this absorbed energy is released then it can lead to ignition somewhere in the depth so you do not want that and therefore you will try to make it as opaque as possible using carbon black and a typical composition of this heterogeneous or homogeneous propellant will have.

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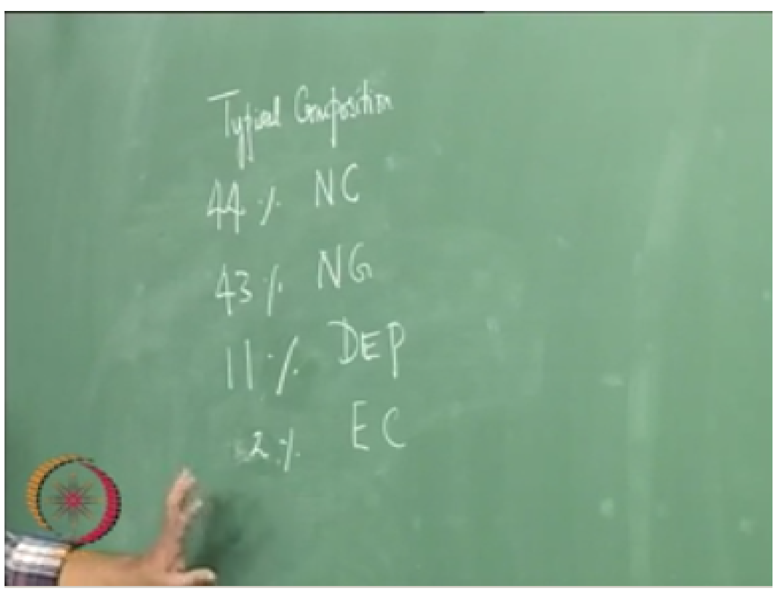

If you see that they are used in nearly equal this thing and therefore the name double base propellant also then de P stands for diethyl maleate in okay and say nitrocellulose and nitro glycerin EC stands for ethyl centralite okay, and a small quantity of carbon black okay this is already fills up, so you can reduce one of it and add a little bit of carbon black to make the propellant opaque Nolan yeah one of them you can add you can add one of them and then he gives you certain burn rate.

Increasing burn rate there are also burn rate suppressors I also talked about something known as visible flame suppressants, so typically for visible flames our presenters potassium nitrate or potassium sulfate okay, now let us look at what is the composition of our composite propellant.

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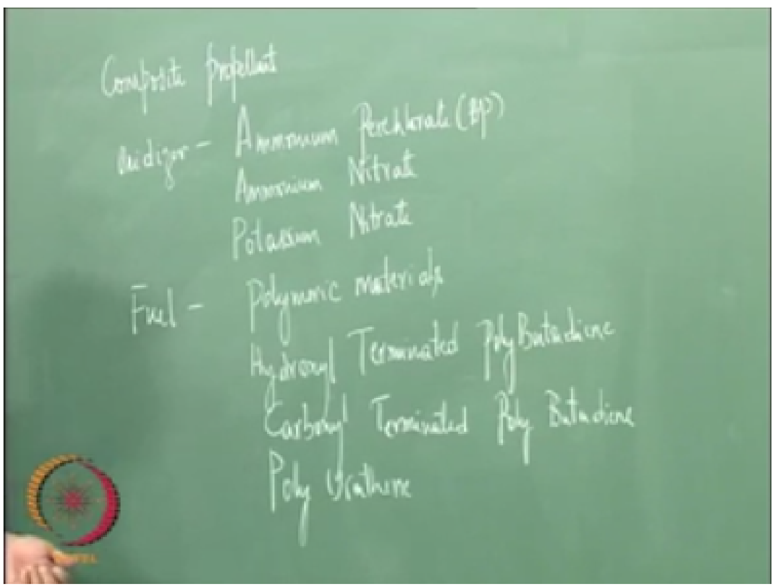

Composite propellant or heterogeneous propellant as I said earlier this is a mechanical mixture you will have oxidizer the typical oxidizers used a ammonium perchlorate also known as AP ammonium nitrate then potassium nitrate okay these are the typical oxidizers then you have polymeric material that is used as the fuel in this case, so the typical ones that are used are hydroxyl terminated poly butadiene then carboxyl terminated butadiene and you also have polyurethane okay these are typical polymeric material they are also known as binders in addition to this fuel.

You also add something known as curing agent typically you will use a monomer of this and then you will tend to make it into a polymer by adding this curing agent, so the typical curing agents used that Tahleen guy isocyanide and I suffering- the Senate these are typical curing agents that are used, so as to make this into a long-chain cross-linked polymer okay they also add plasticizers here -to improve the mechanical properties DOA which is dioctyl adequate.

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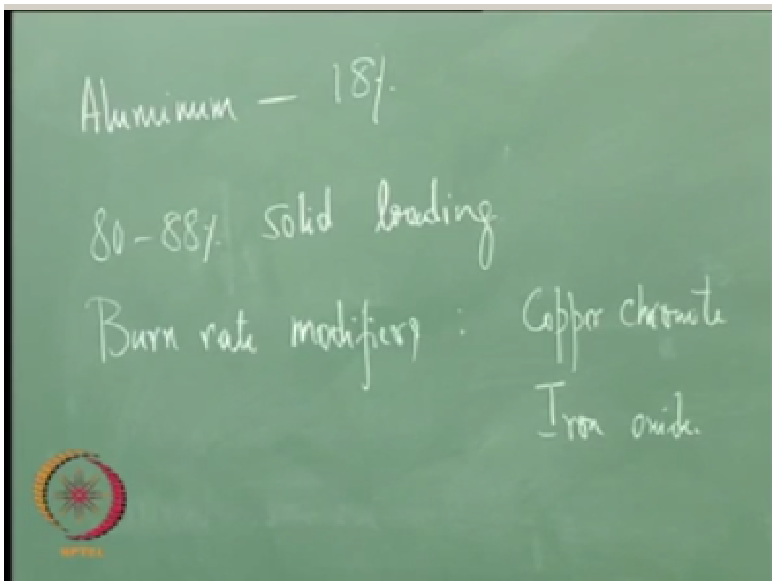

This oxidizer I said he is around is added this is a particle it matter, so if you look at the oxidizer these will be particles ranging from somewhere around typically 400 microns to typically 10 microns there is a distribution that we use and, if you look at a typical cross-section of propellant this.

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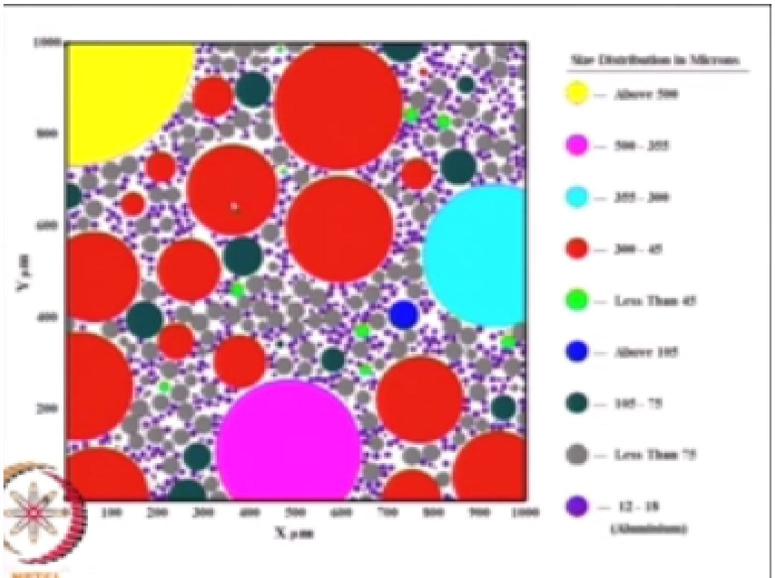

What I have shown here is a simulated propellant that is I have assumed all the particles to be spheres the perfect spheres and I have simulated it for something like 85% of solid loading that is 85% of this propellant is filled with solids as you can see there are different sizes of particles one is above 500 then 500 to 355 and all the way going up to less than 75 microns.

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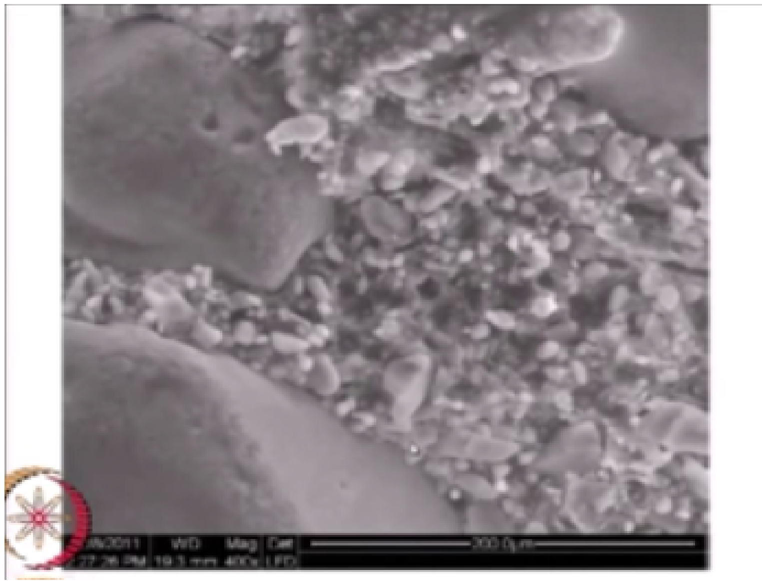

Now why do we need to have this kind of variation in particle size that is primarily, if you look at it if you have only large spheres you cannot have a loading beyond certain fraction and if you have small spheres also you cannot have loading beyond certain, fraction if you use a combination you can go to a higher fraction of loading that is why we use this kind of coarse and fine particles to get the required loading as I said you also add something like 12 to18 18 % of aluminum is added.

Now this is added in a composite propellant essentially to improve the specific impulse of the propellant the specific impulse of the propellant improves because, if you add aluminum the chamber temperatures that are reached are much higher than without it okay, so you will get to higher the chamber temperatures and therefore your specific impulse will improve this also has another rule that is it is known to be a combustion instability suppressant okay we will talk about it probably a little later in the course.

Now you can see aluminum particles that are in purple here they are in large numbers and have distributed all over the propellant okay this is how a simulated propellant looks and if you look at an actual propellant it looks something like this is a scanning electron microscope picture these are coarse particles here coarse particles and you also have fine sized AP particle and also aluminum particles okay so all of it is present and whatever is not occupied by the solid that is occupied by the binder or the polymer, so this will give rise to something like 85% solid loading okay and the remaining 85 to 86% solid loading or sometimes 88 % is also used, so this ranges from 80 to 88% solid loading this is you also have here to burn rate modifiers the typical burn rate modifiers.

Used are copper chromite and iron oxide, now with this you will have a composite propellant now we have looked at both the composite and homogenous propellants in the next class we look at how this can be used in a propellant, and what is the burn rate that one can get with these propellants and what is the function what does burn rate depend on okay and also how does pressure vary in a rocket motor because of this all that we look at it in the next class thank you.

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