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Indian Institute of Technology Delhi

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Video Course on
Advanced Textile Printing Technology

by

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IIT Delhi

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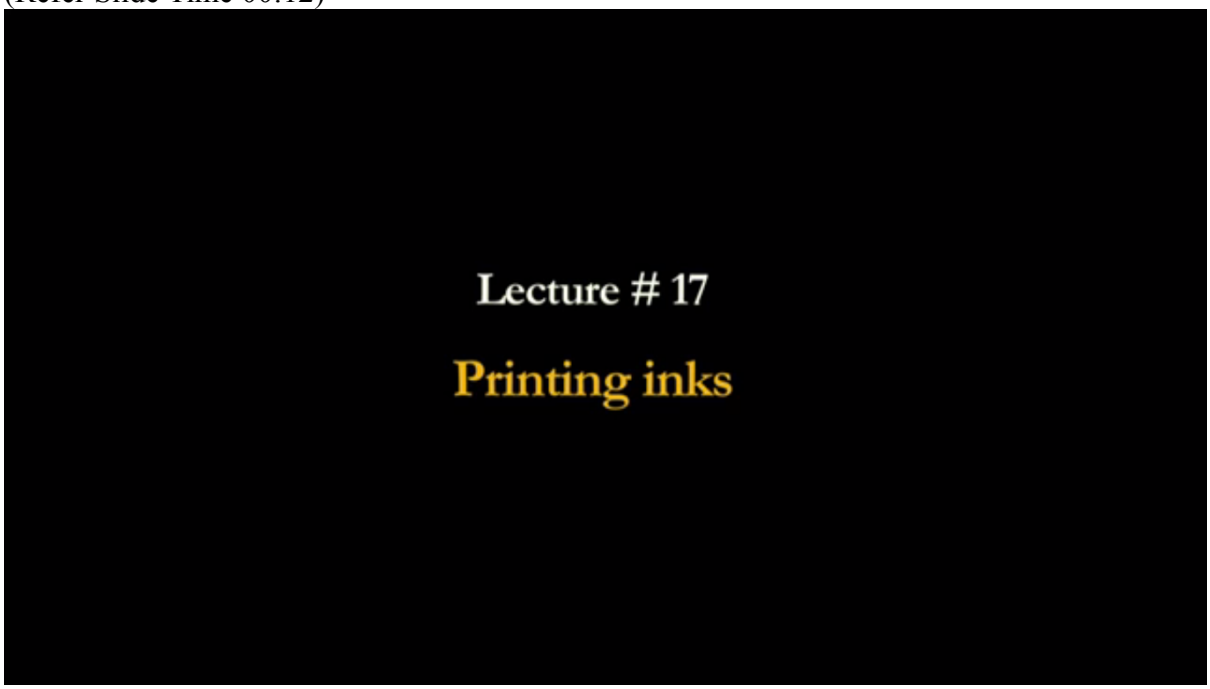

Lecture # 17
Printing inks

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Welcome back to our lecture series on advanced textile printing technology, continue from where we had left last time.

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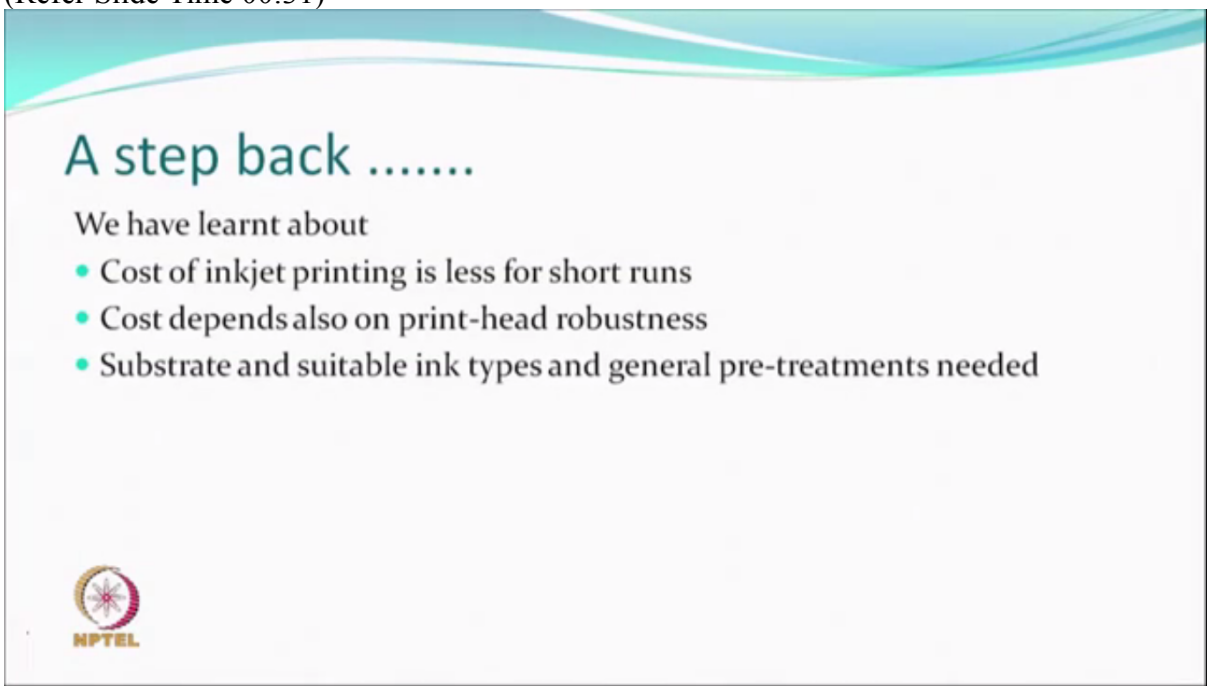

So what did we do last time? We learnt about the cost of inkjet printing and we understood that for short runs it's definitely less than the regular printing techniques. The cost, of course, depends on the print-head robustness, one ink versus the other ink, aqueous ink versus the non-aqueous inks or continuous jet, inkjet systems versus the DOD systems. All that, of course, will have some role to play.

Substance that is the substrate and the suitable ink type and in general pre-treatments that we need to do are the ones which are going to be responsible for the cost.

We move further.

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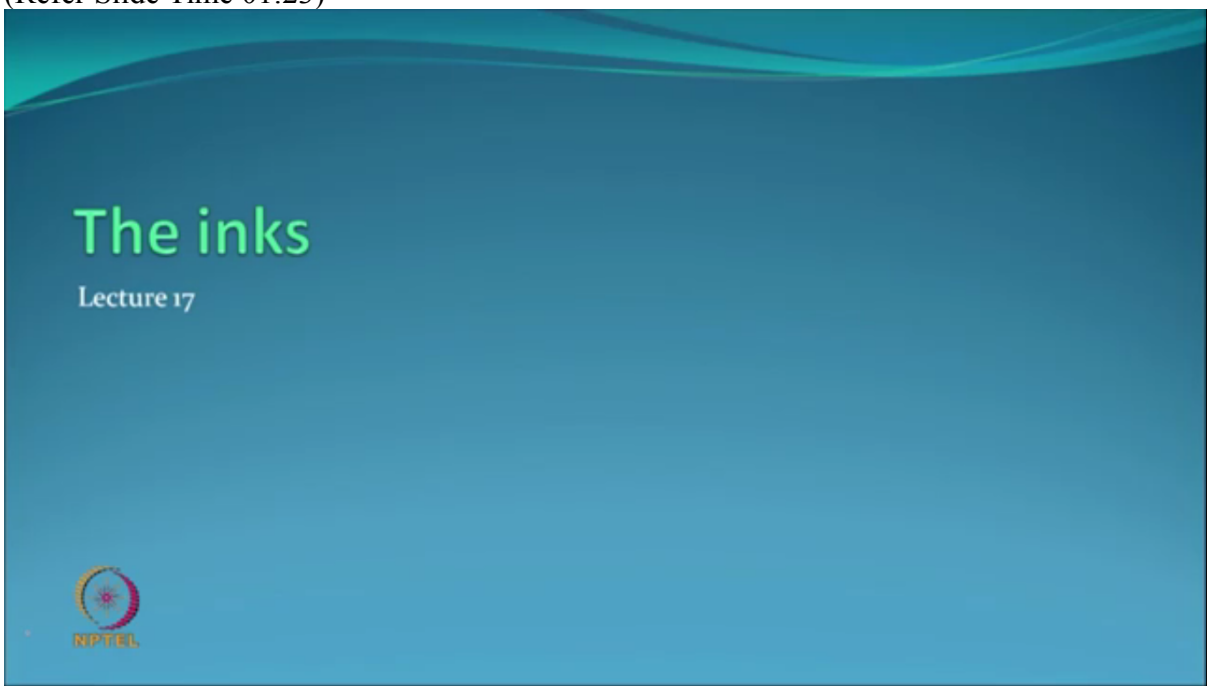

We talk about inks little more. Inks as we know, basically, are the main stay of this inkjet printing and so general properties of the inks are going to be more important for everyone to learn.

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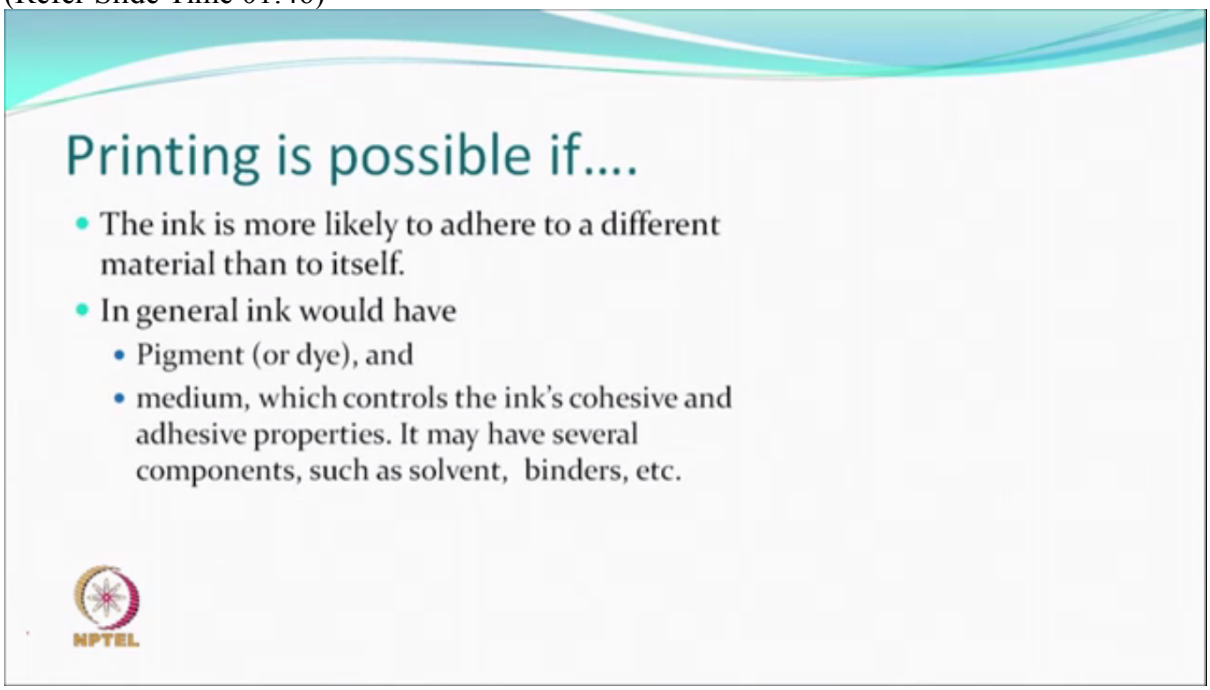

So we do not have any doubt on this that printing is possible only if the ink is more likely to adhere to a different material than to itself. So, in general, ink would have a pigment or a dye,

which, of course, is what is needed and of course there's going to be medium, which controls the ink's cohesiveness and adhesiveness. It may have several components within this solution of which is called the ink. It could be binders. It could be solvents and many other things, which would change the behavior, the flow behavior of the ink.

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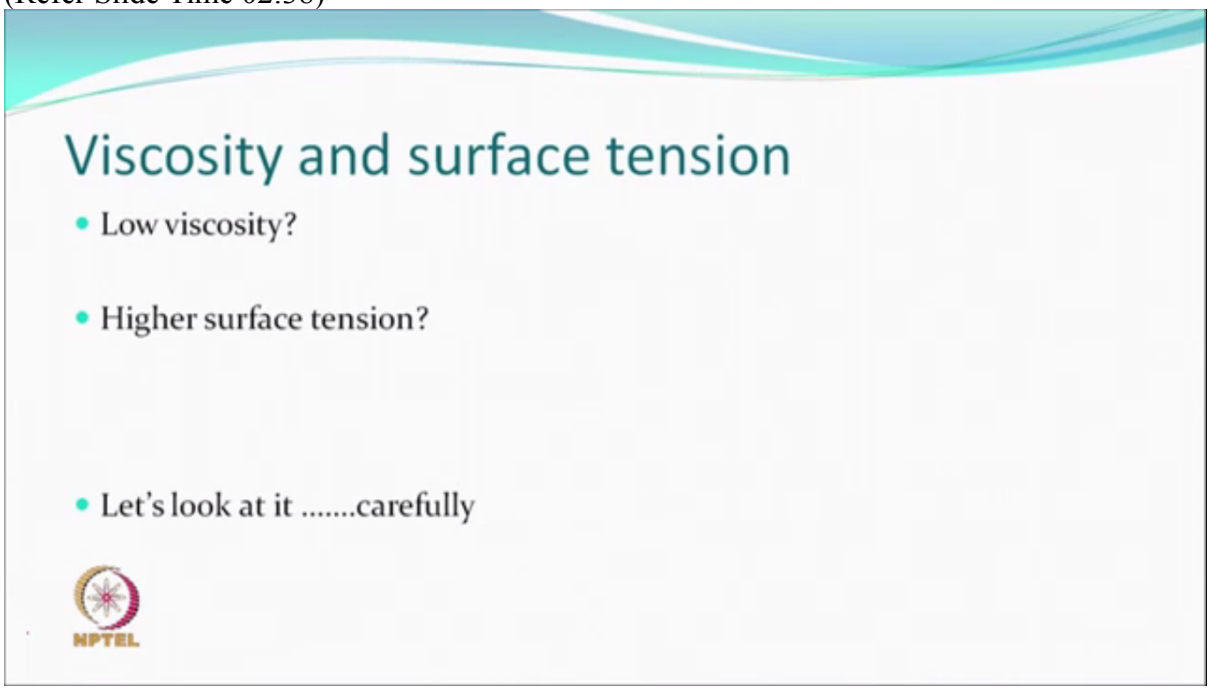

In general, the viscosity and surface tension are going to play an important role. You can appreciate that the inks which we use for inkjet printing are low viscosity systems. If it was a very high viscosity system, then, obviously, it will not pass through, unlike, for example, our conventional printing.

So conventional printing uses print paste which have very high viscosity. So we are much away from that. It's a very low viscosity system and surface tension is generally we expect it to be higher. What do we mean by that? If the surface tension is higher, this drop as it comes out will become spherical and then the dot which is going to be created will be more circular. So if the surface tension is very, very low, then it may have a tendency to spread. So we would generally prefer low viscosity, high surface tension. So let's look at it little more carefully as to what exactly would we mean by that.

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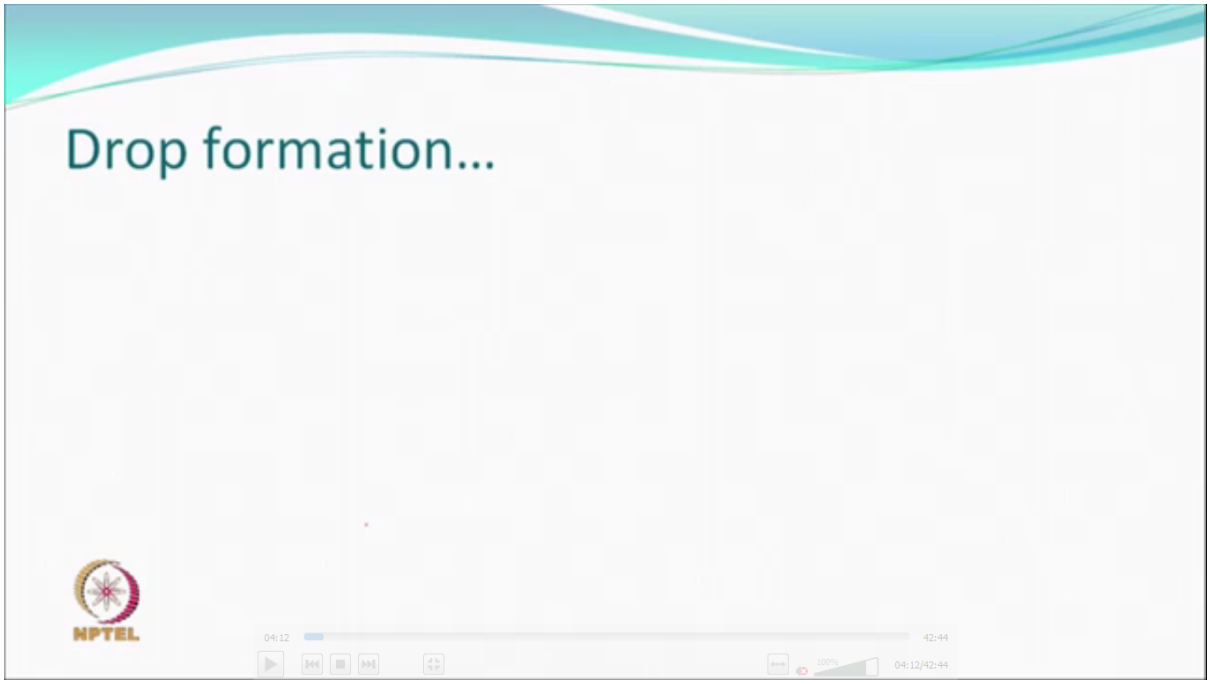

Let's look at how the drop is formed. So there is actuator, which may be piezo-based actuator or any other actuator, thermal actuation, which puts a bit of a force onto the system so that the drop is thrown out.

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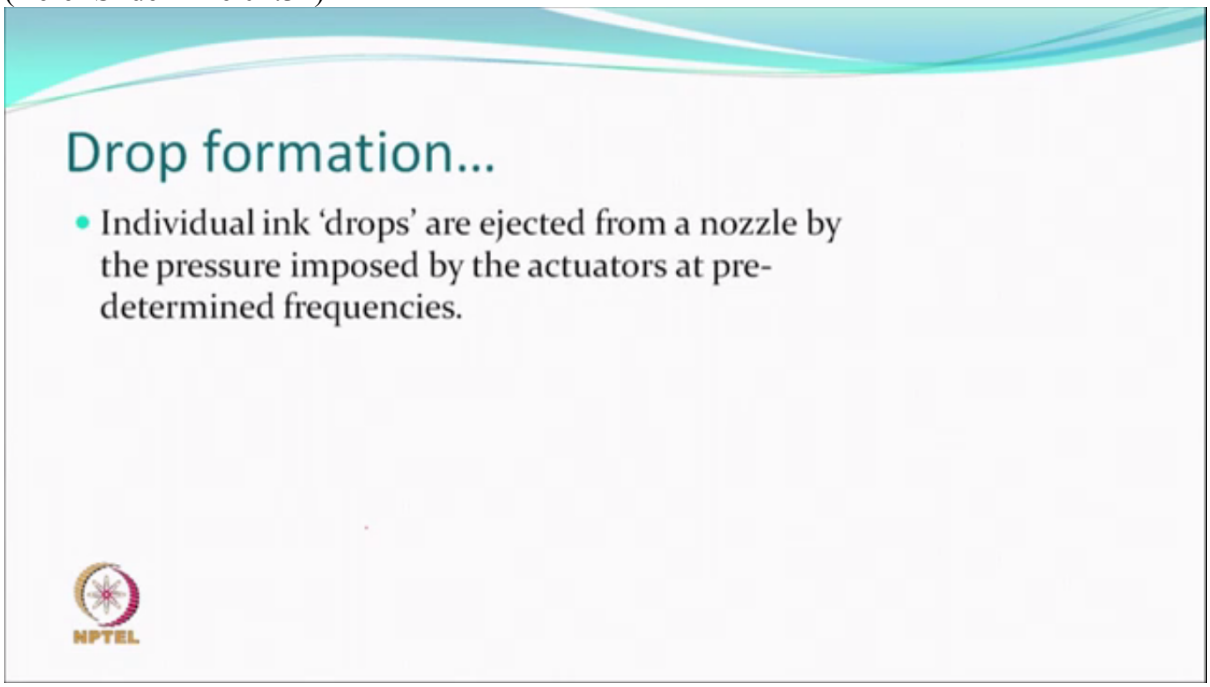

So what happens is individual ink drops are ejected, okay, from the nozzle, and you apply a pressure and the pressure is by various actuators add frequency, which are predetermined, like we already probably know that the DOD type of machines or systems require less frequency compared to the CIJ types, and so based on that frequency, there are going to be pulses, which are going to be ejecting the drops.

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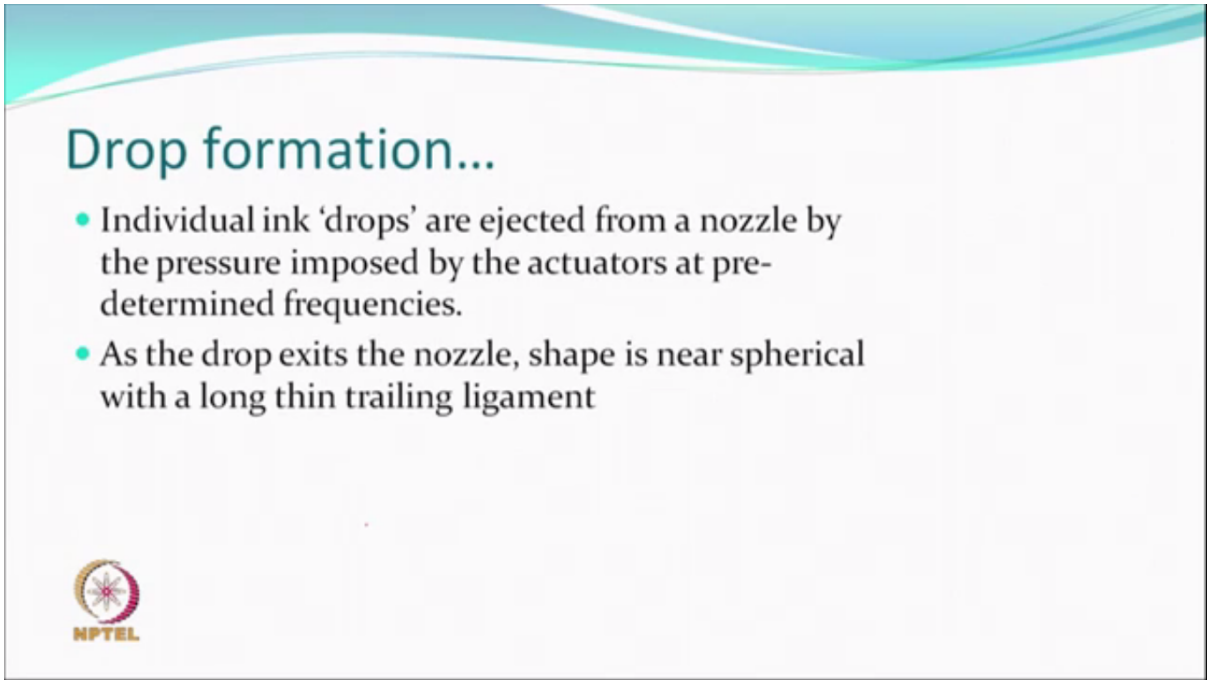

And as the drop exits the nozzle, the shape is near spherical with a long thin trailing ligament. For example, if this is the exit of the nozzle, the drop initially may come like this. As it moves further, so it may actually have a spherical thing with something which is extending we are calling as the ligament.

So at some stage it has to break. What happens when it breaks? This trailing ligament, which is attached, it has to break. So when it breaks, part of it will go to this and part depending upon where it broke may go back. This is how the drop may like to form.

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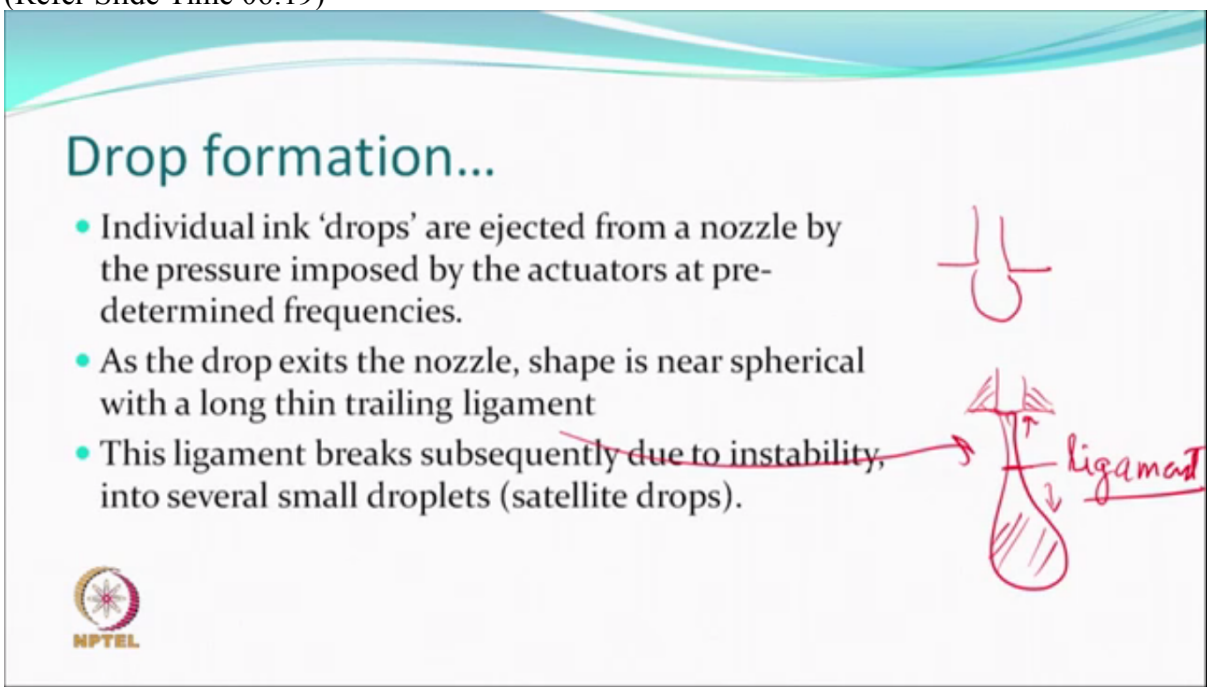

We expect that the ligament breaks subsequently due to instability because there is gravitational force and the push which is taking it away, and then it may, while it is breaking,

may also create something which we call as a satellite drop. Small, small droplets also while you may have a big drop which is going to become spherical and small drops as it is breaking may also get created, right, and this will be then called like satellite drops.

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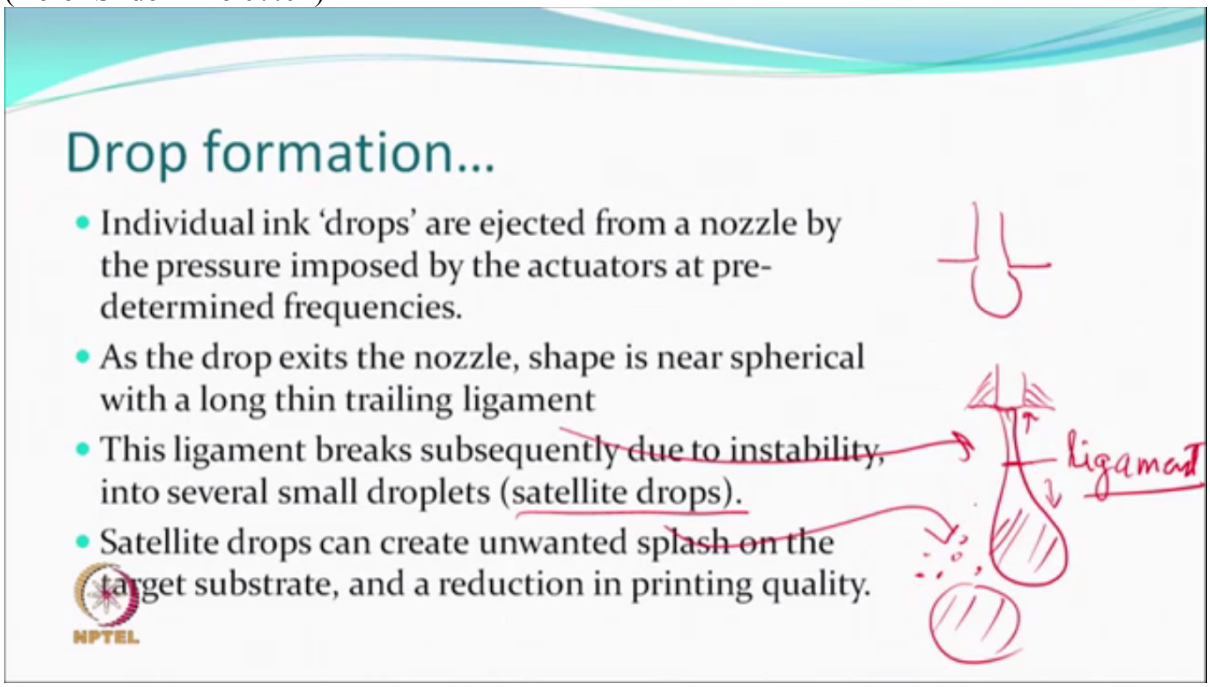

I don't think it's a good idea. Satellite drops can create unwanted splash on the target substrate, whether it's a paper or a fabric, and this obviously means there is a reduction in print quality.

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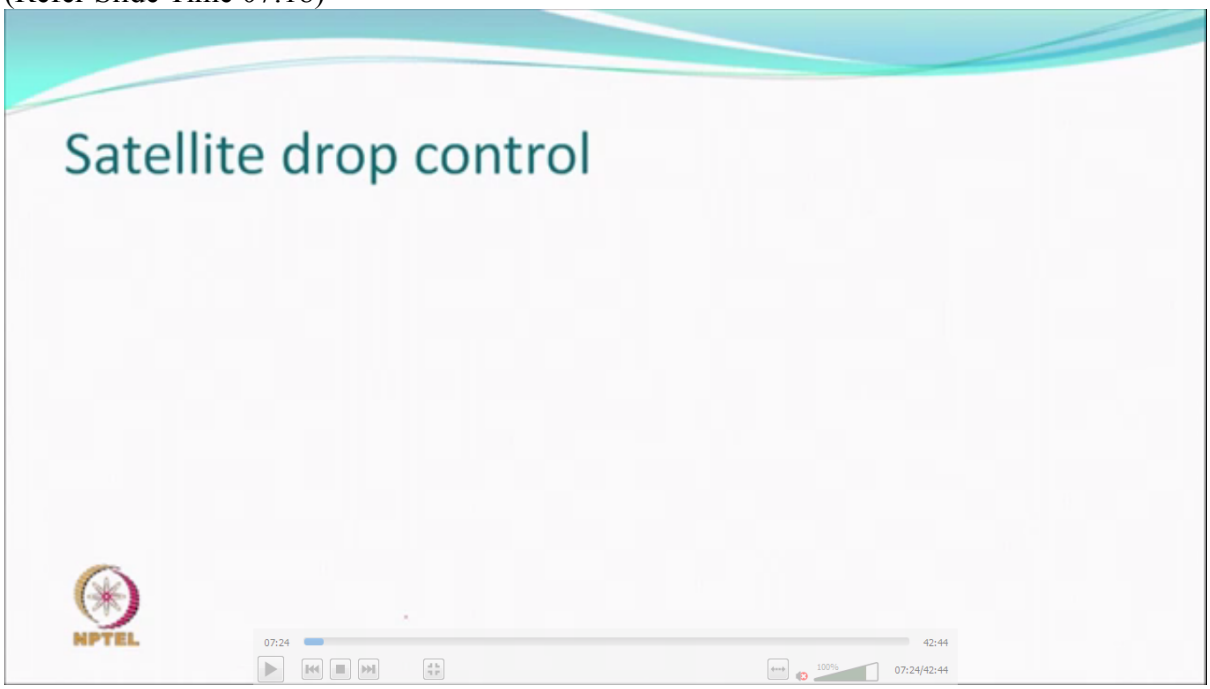

So how do we control the satellite drop formation? We want to control this.

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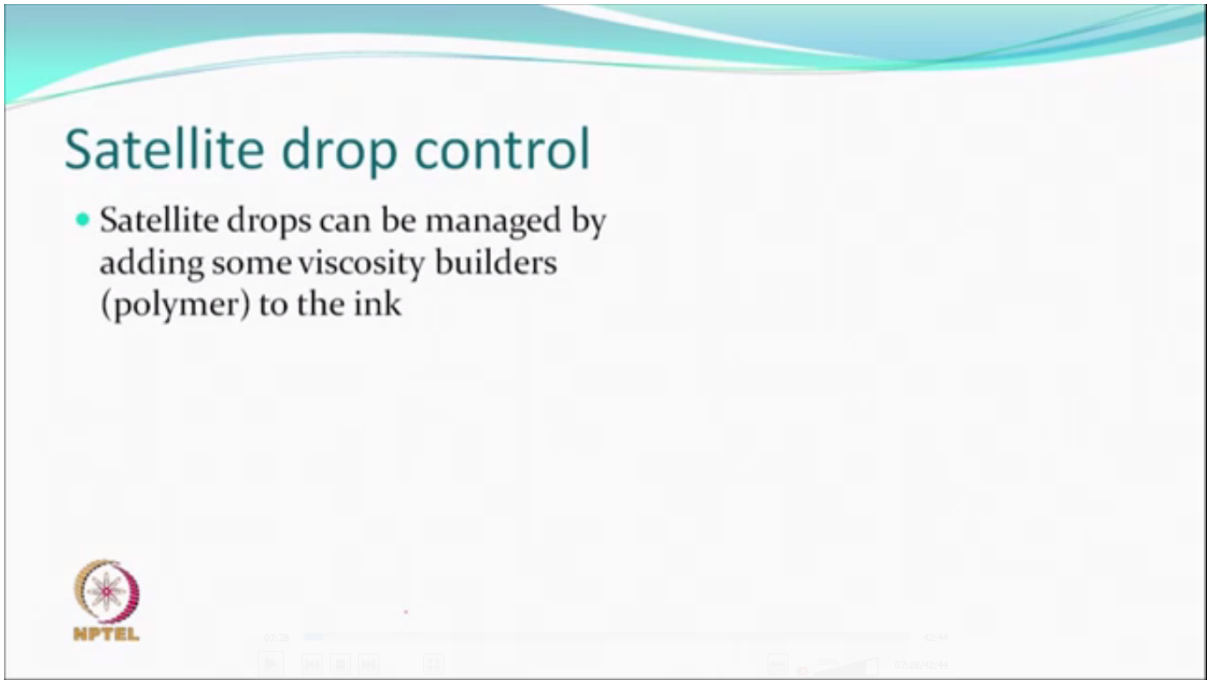

So one of the ways is that you can add some viscosity builders and what is the viscosity builder? There may be some kind of a polymer, which obviously increases the viscosity of the ink. Now this helps to a great extent because then what happens is that this so-called ligament, when it breaks, would have a tendency to shrink towards this and not break into satellite drop. So a bit of a change in viscosity can change this behavior and you may not have satellite drops being created.

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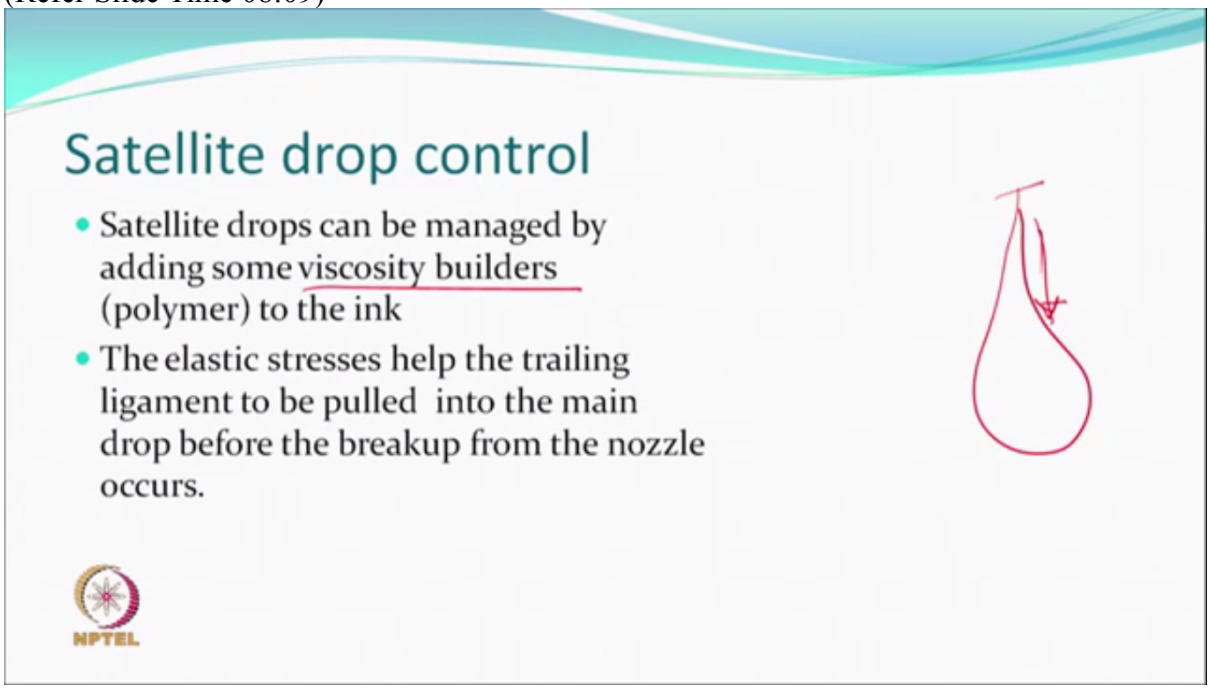

So why does it happen? So because of this small little increase in the viscosity, there are elastic stresses, which help this trailing ligament to be pulled back, okay, to pull to the drop itself and before breaking up from the nozzle. So this is one way the ink manufacturer would like to control which definitely will help in the quality of the print produced.

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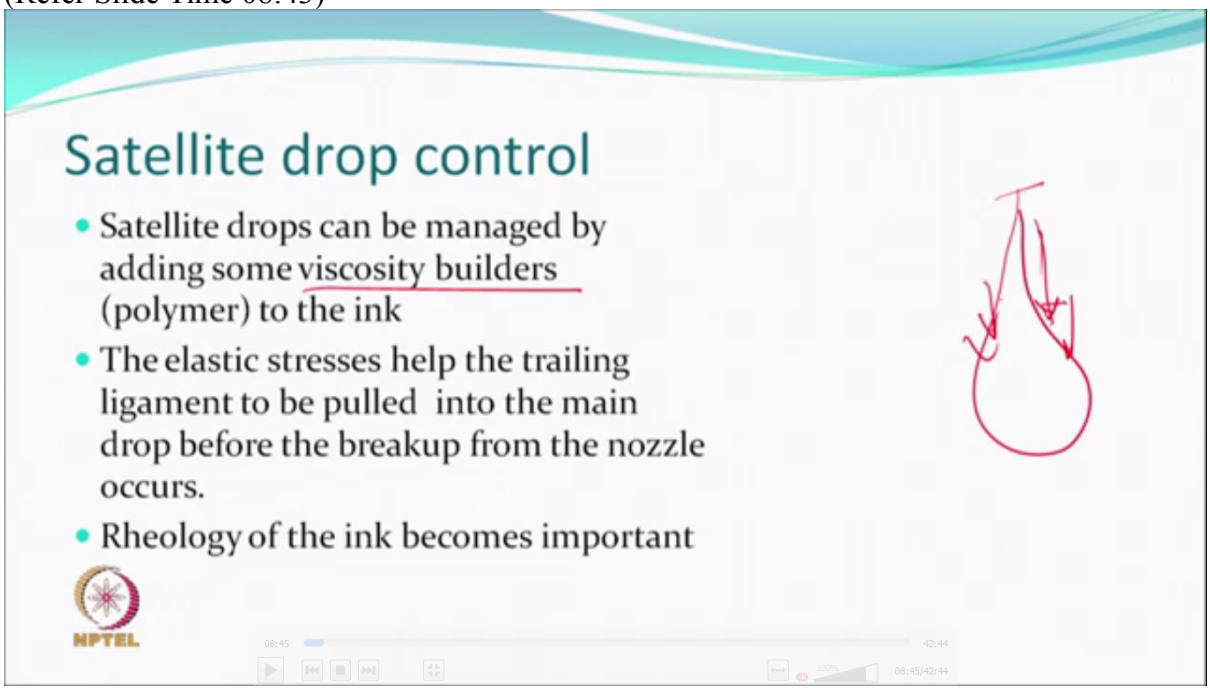

So what becomes important? The rheology. Normally, people will say, well, you are working with a very low viscosity systems and how the rheology becomes important, but that does become important.

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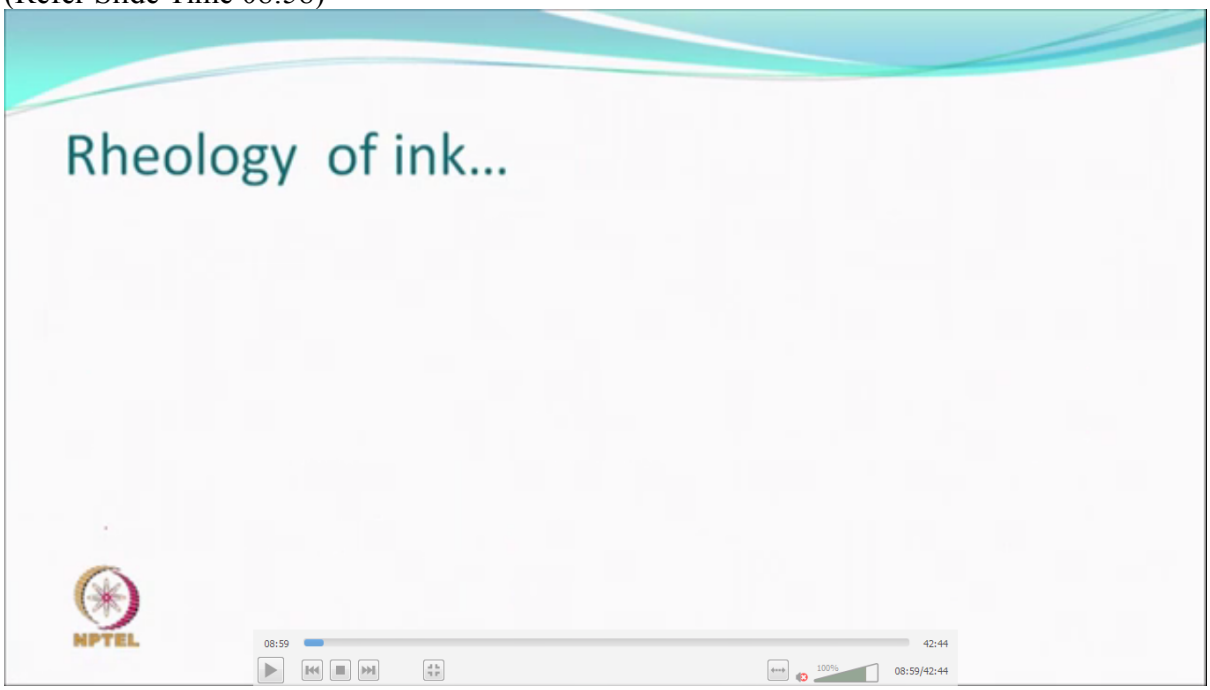

So let's talk little bit about the rheology of ink.

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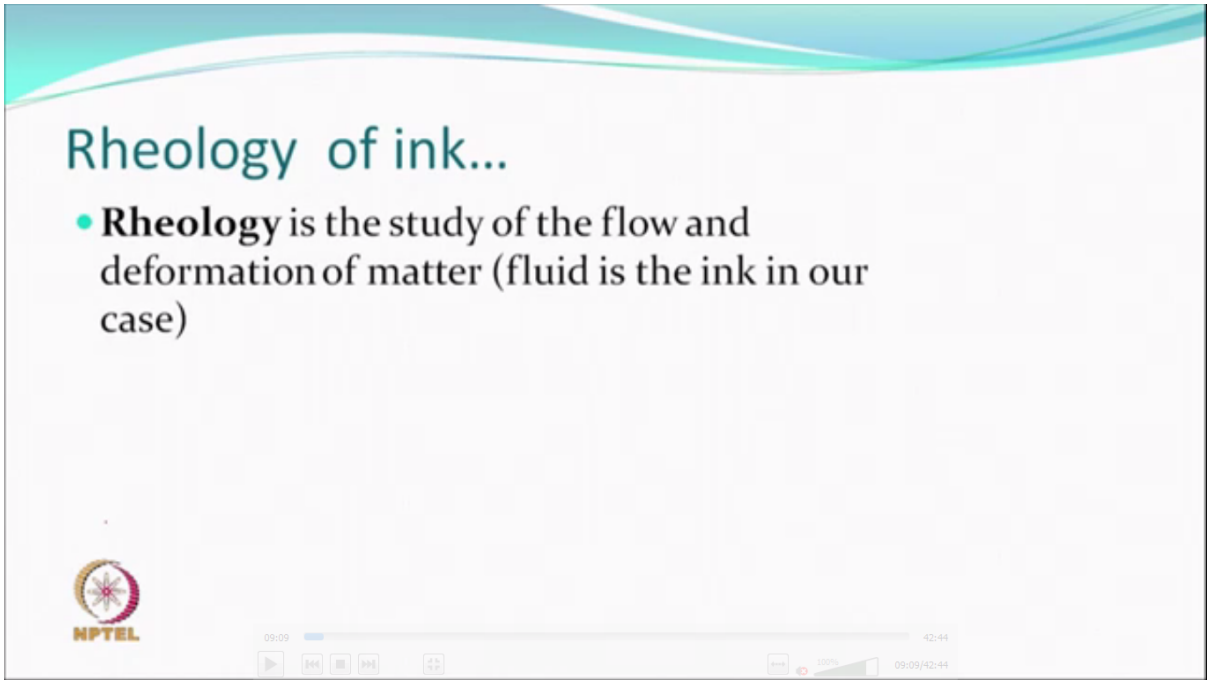

So what is rheology? It's a study of the flow and deformation of a matter. In our case, it is the ink, which is flowing through a nozzle.

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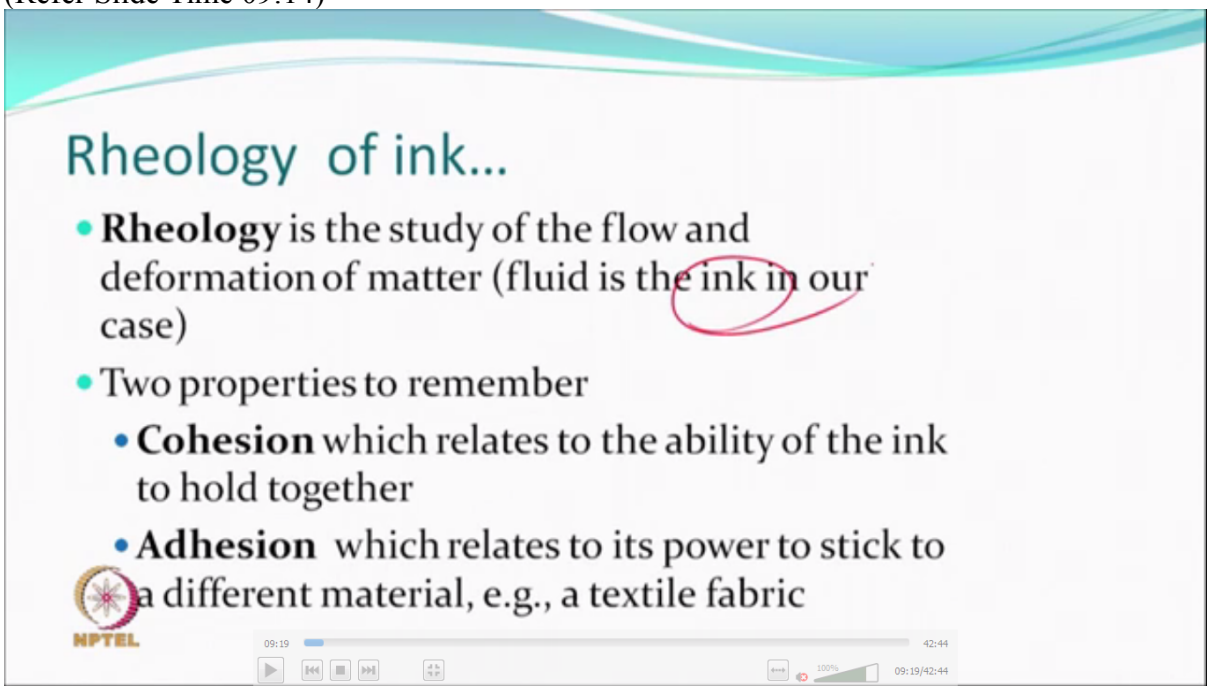

The two properties are important. One obviously cohesion, which obviously relates to the ability of the ink to hold together and the other is adhesion, which relates to its power to stick to a different material. In our case, it could be the textile fabric. So, cohesion, so that the ink or a drop remains as a drop or becomes a drop. Adhesion is the property with which it adheres to the other material, which is the textile fabric. These are the two things we will be expecting.

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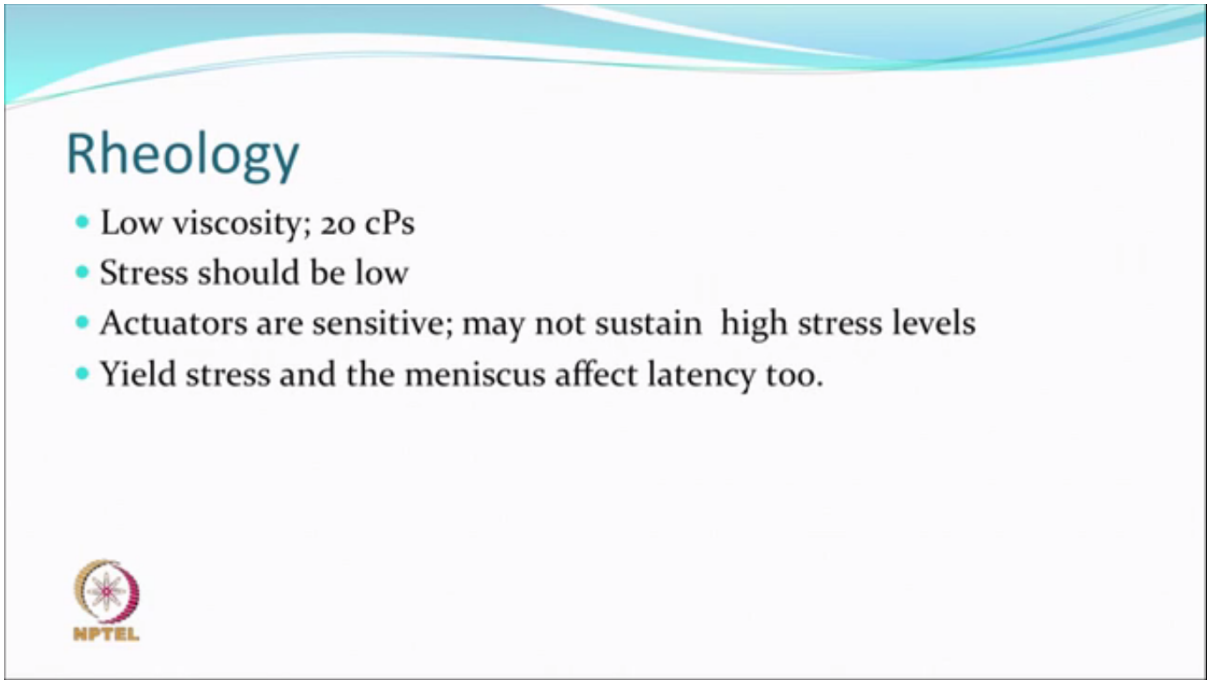

As we mentioned earlier, we are dealing with low viscosity system, which is approximately equal to 20 cPs. The stress should be low again. Why? Because we are working with very, very minute actuators, which may not be able to sustain very high stress levels. So what does it mean? It means that we will still want the viscosity or the rheology to change in a manner that the ink flows much more easily when required so that the stresses on actuators are less.

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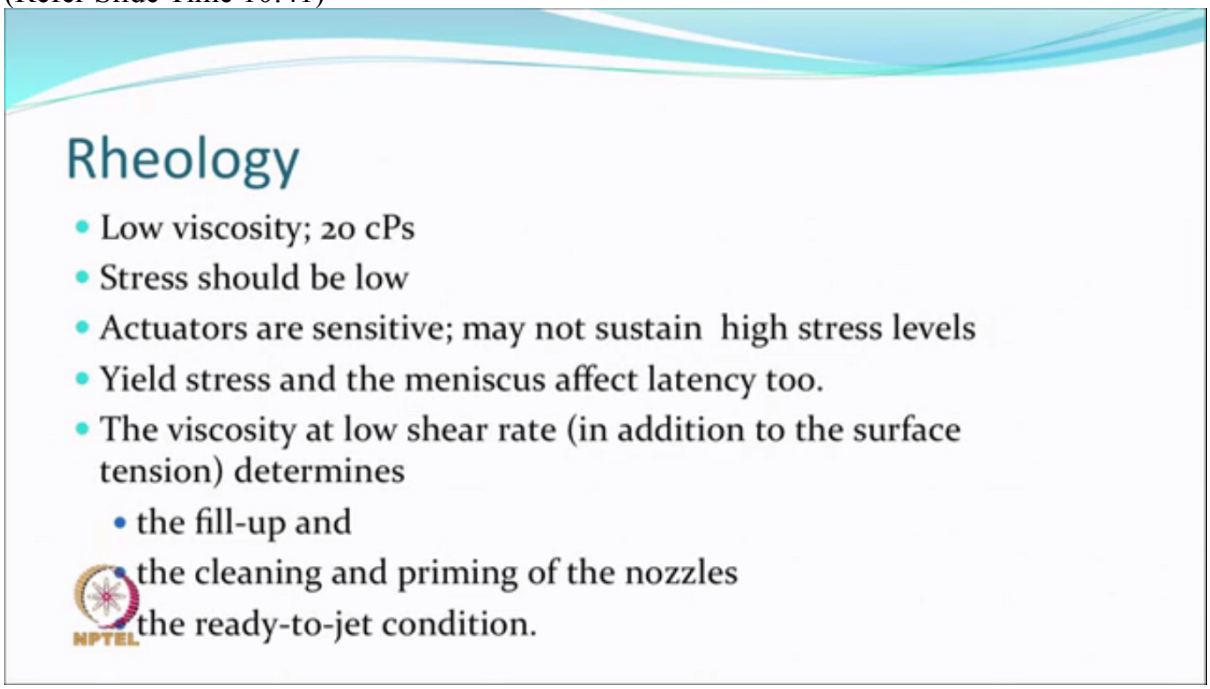

Yield stress and the meniscus affect the latency. That means whatever polymer system that we are going to be adding, they will modify the rheology.

Viscosity at low shear rates (in addition to the surface tension) they determine the fill-up. Fill-up means whenever some volume goes out of the chamber, something must come back.

Cleaning and priming of nozzles because this is important. There is a station at the end where the printhead goes and rests at the end of the machine.

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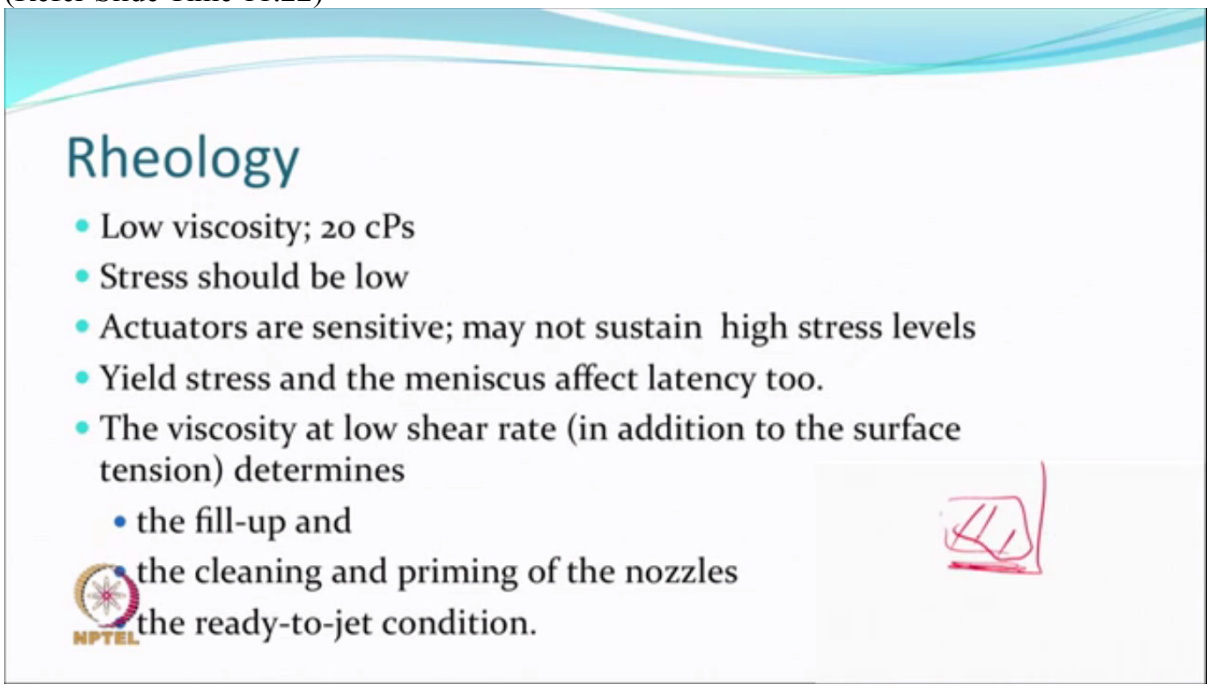

Here this is called priming and here there can be some cleaning also happening so that the next time when it goes for the printing to the other direction, the jetting is very nice. So it is always in a ready to jet condition.

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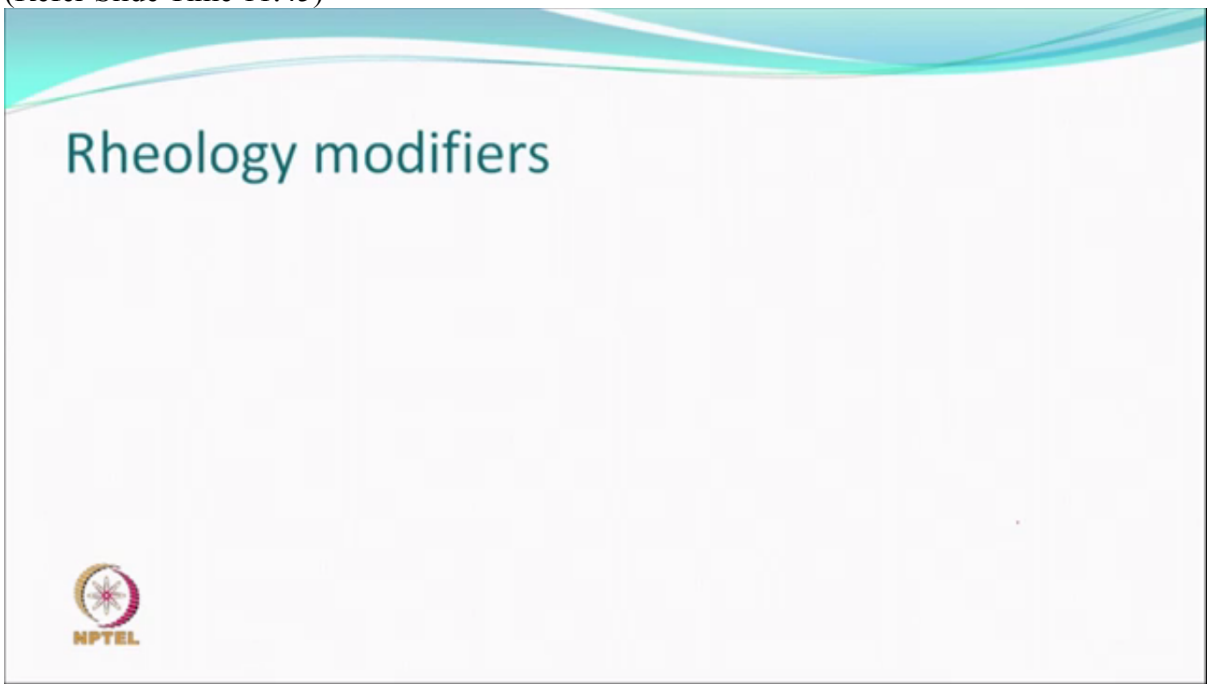

So we just talked about some polymers being added. So these are also called rheology modifiers. We just understood why it would be needed. Maybe this would help us to reduce the satellite drop formation.

Viscosity of the ink will change a bit, of course, but still not so much, but little bit. Small little changes will take place. The some of the materials which can be used as rheology modifiers are like polyethylene glycol. The molecular weight could be ranging from several hundreds up to hundreds of thousands can be used as the rheology modifiers.

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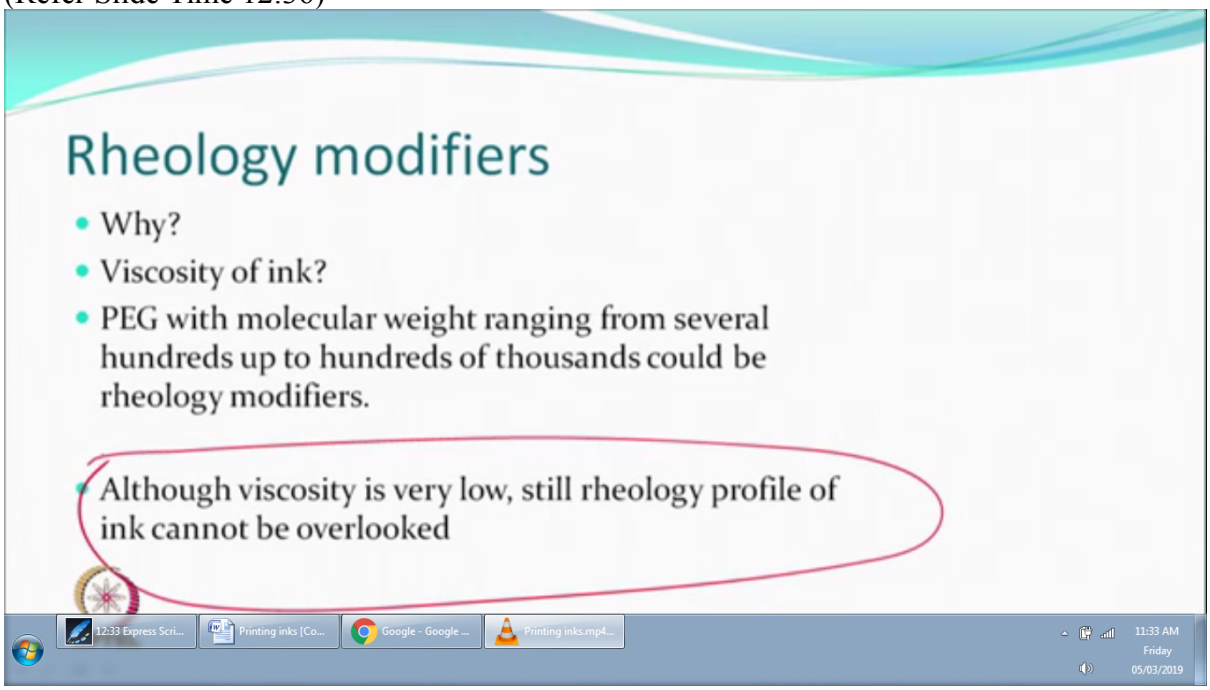

So remember although viscosity is low, the rheology is very important and we cannot be ignored. We cannot ignore the rheology of this ink, which actually has a low viscosity.

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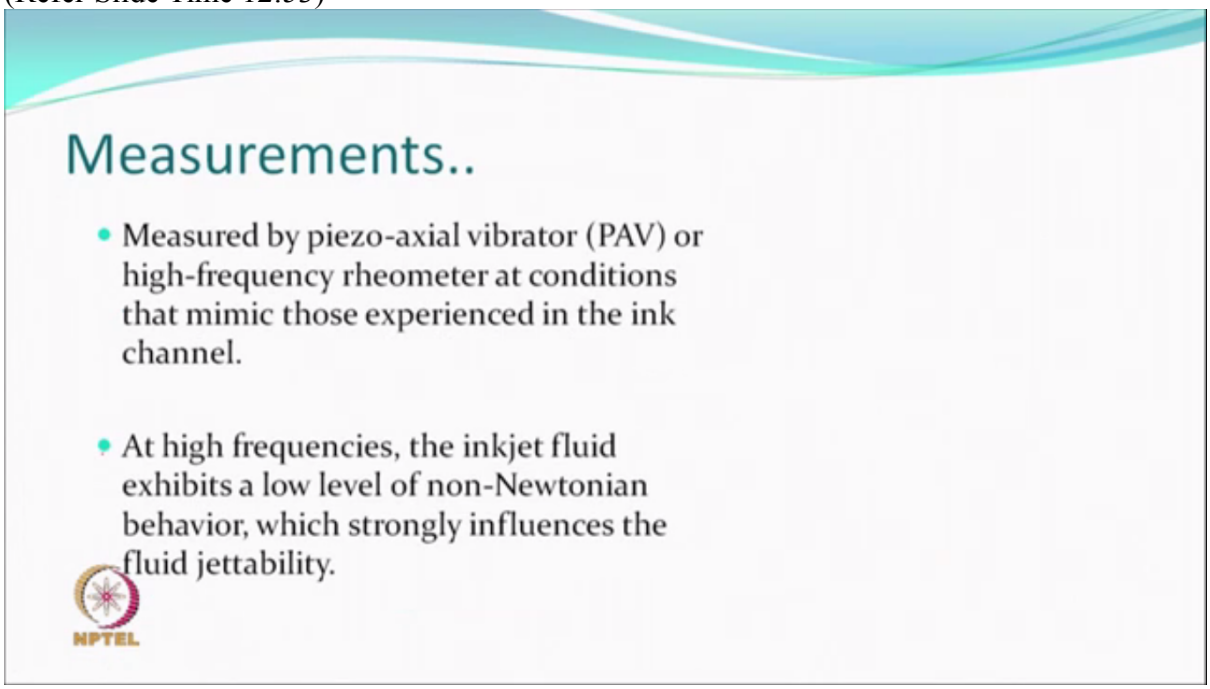

And so the measurements, which are done of viscosity, the method that we use earlier may not be very suitable for this type of a material because the ink is experiencing various types

of pulses, pushes by actuators at frequency, which are very high frequencies and therefore the behavior should also be test by instruments which work at high frequency, for example, high frequency rheometer, a condition which can be mimicked by these rheometers which are approximately the same type of condition which the ink experiences in the channel.

At high frequencies, the ink jet fluid exhibits a low level of non-Newtonian behavior, which also strongly influences the jettability, fluid jettability.

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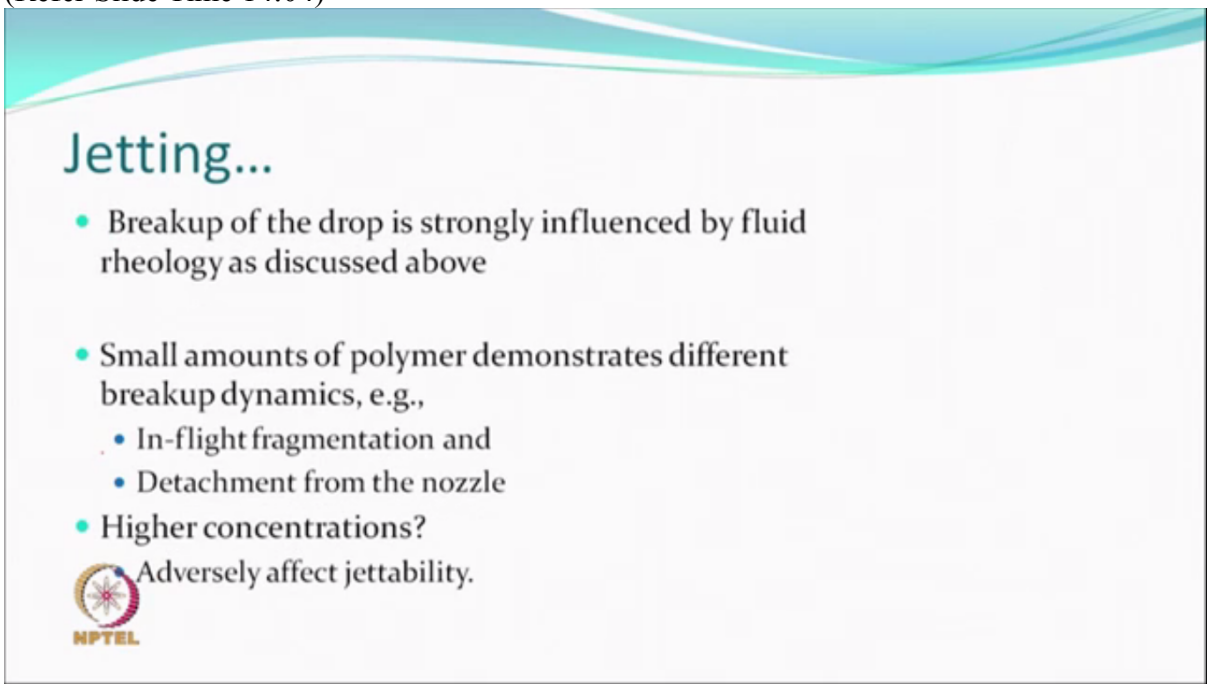

So now we have the term jetting, which sometimes people used, ready to jet. So, basically, this refers to break up of the drop is called the jetting, which gets influenced by, obviously, as we said rheology as discussed just before.

So small amounts of polymer demonstrates different break up dynamics so which means in-flight fragmentation when it has just been detached and how fast, how readily, how easily the drop gets detached from the nozzle. So that's what is jetting.

If we add polymers which are in higher concentration, obviously, it may not be a good idea because it will adversely affect the jettability. In fact, if you have too much of polymer, it can clog the nozzle itself.

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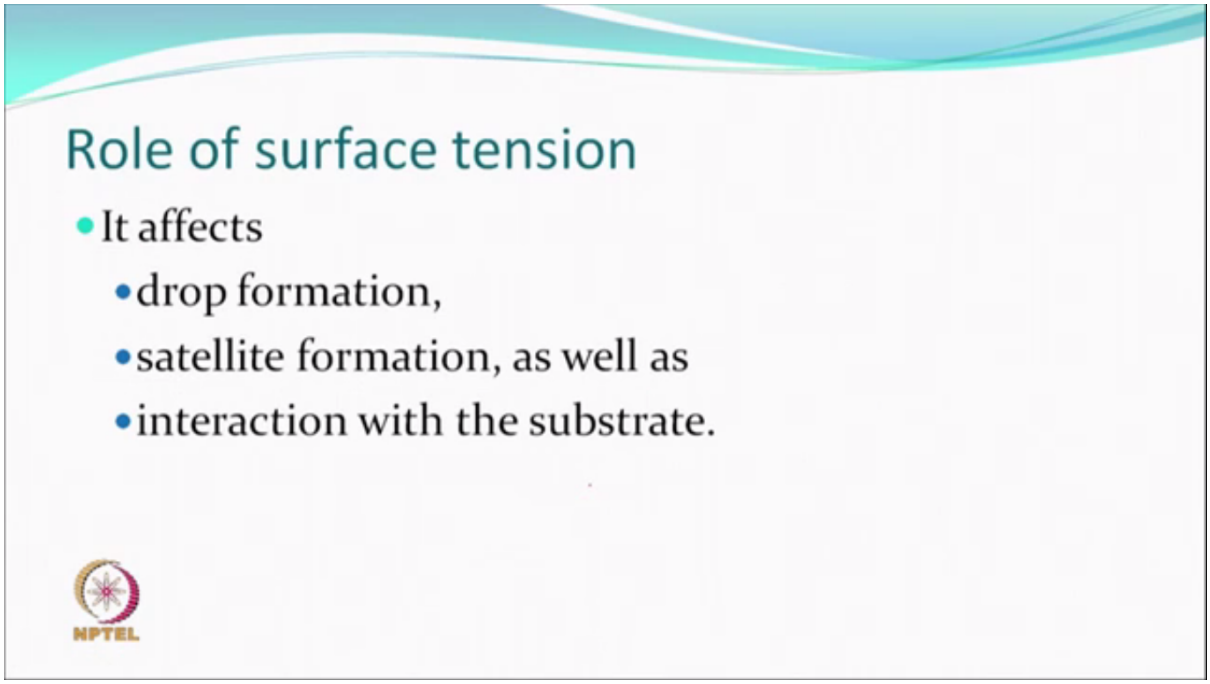

So then the other property is surface tension. You can understand very easily that surface tension affects drop formation. You can appreciate why is drop formed? It is formed because of the surface energy, which becomes the least when it is spherical and if it also would help or look at the behavior in the satellite formation, if it is very high, then every small droplet that get created also becomes a satellite. If it is a very, very low surface tension, which is also not very good, because then everything will in a way start flowing.

So an optimum level of surface tension is required because finally we want drop to be spherical and we want the dot to be a circle, a dot which is going to be created on a textile substrate and you can appreciate that surface tension properties would determine whether the drop will very easily spread or it will just stay there where it is before it is dried.

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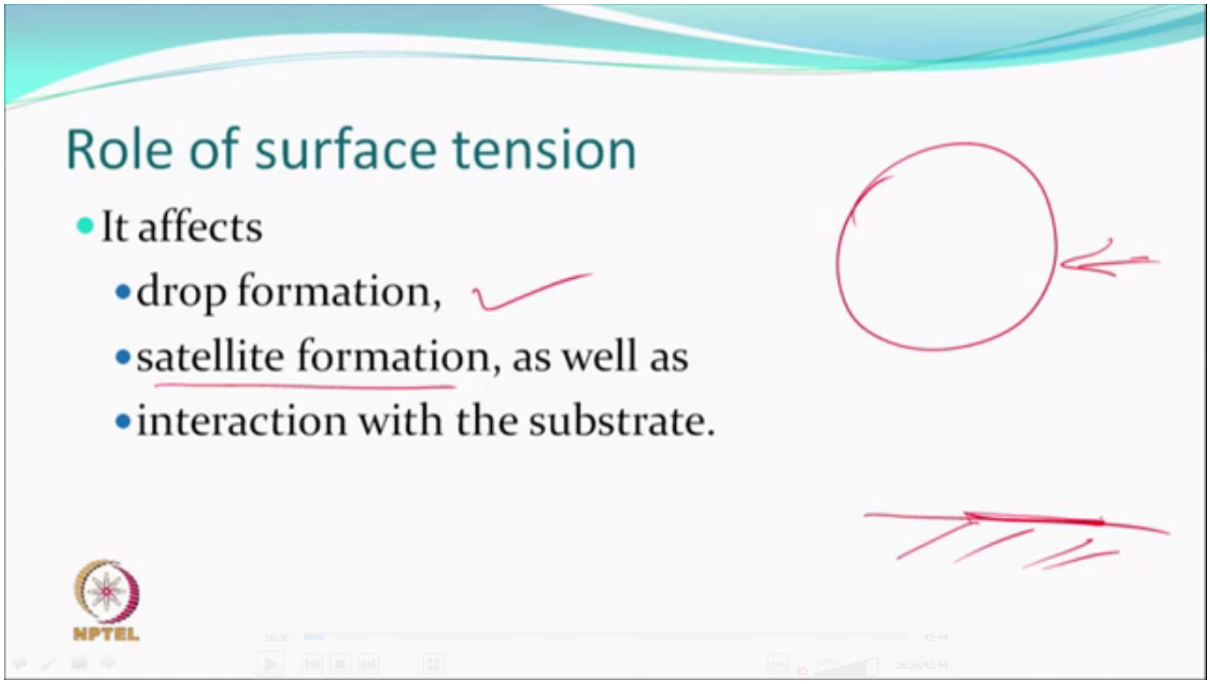

So all the interactions with the substrate also will be governed by the surface tension properties.

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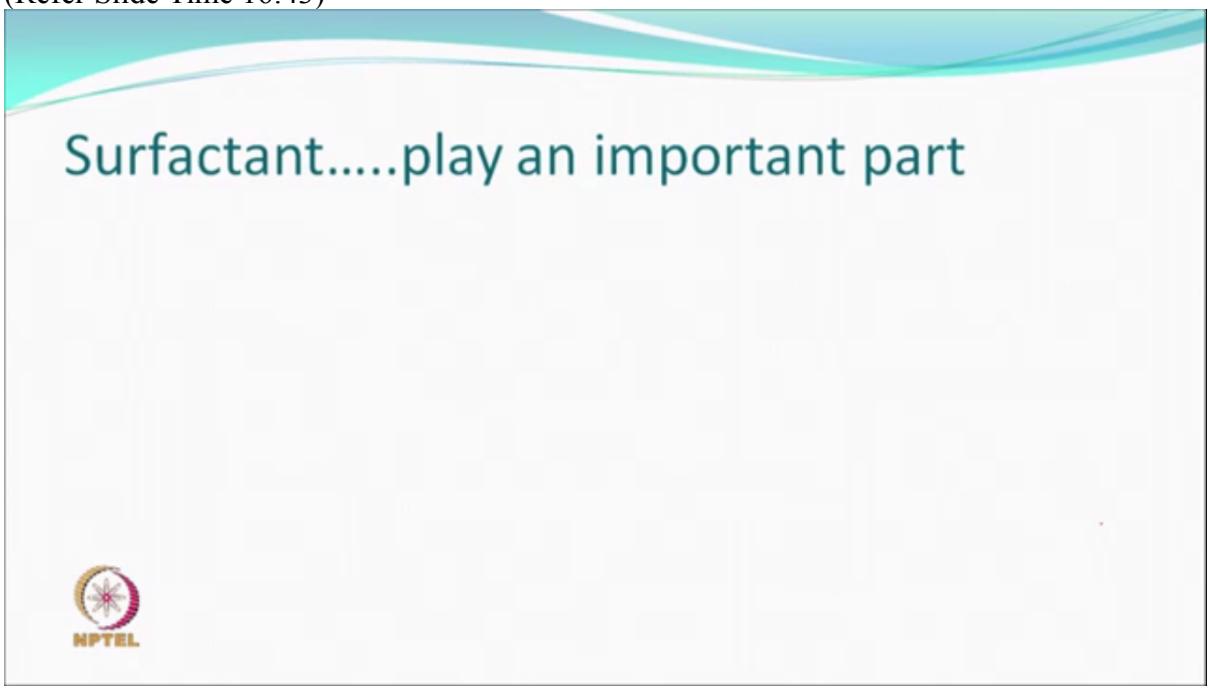

Now in this case, obviously, a surfactant, whatever, for whatever reason you add a surfactant will play an important role because surface tension will change whenever you act -- add any surfactant.

Generally, it is the thumb rule, high HLB value of a surfactant would help stability of a colloidal solution. Collidal can be there because you may be using particles which are pigment particles and something like that.

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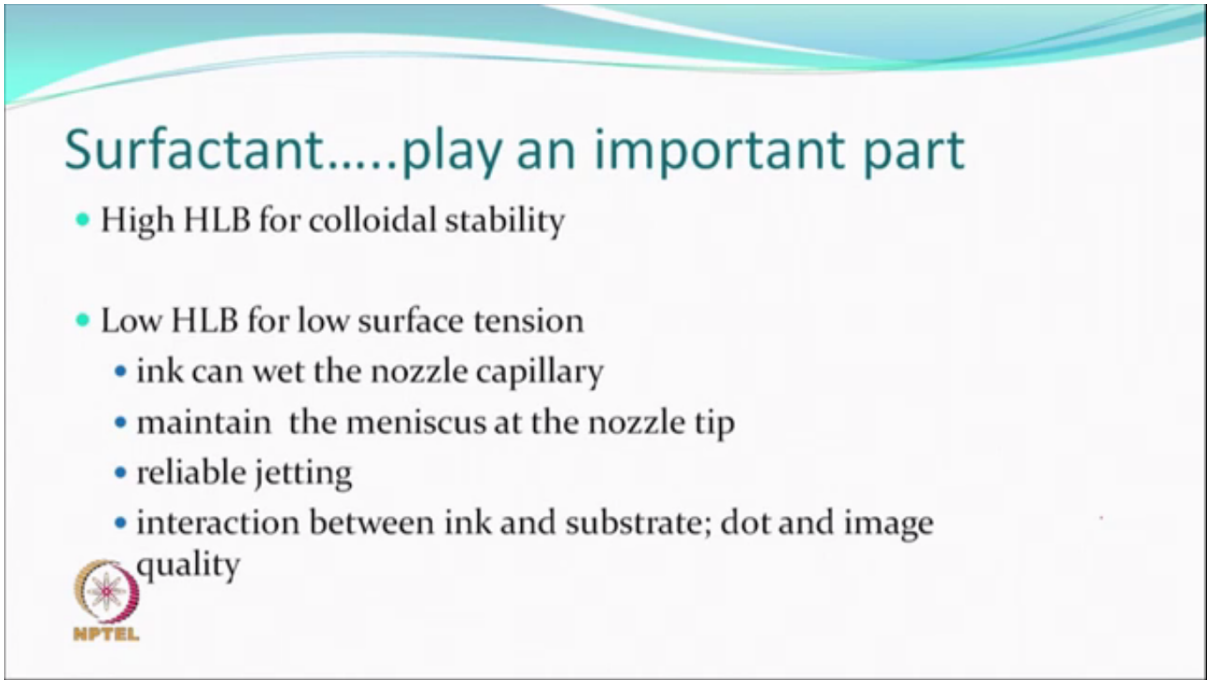

Low HLB value will give you low surface tension. It can also help you to keep the nozzle capillary always wet. It can also help to maintain meniscus at the nozzle tip and it can also be reliable jetting and as we said before that interaction between ink and substrate can also be affected. Dot and image quality, both of them are so important to us.

So what do we do? So you have to do a good balance what kind of a HLB of a surfactant we would want. So it's not going to be an easy thing. So too much high will do the colloidal stability, which can be very helpful for us, but if it is very high, then surface tension and other things are going to be affected. Jetting will be affected and so one may have to do a balance between the colloidal stability and relatively low surface tension.

Here also we have already mentioned that it cannot be in the situation where surface tension is so low that the ink has more tendency to float and the ligaments will be longer and so on and so forth.

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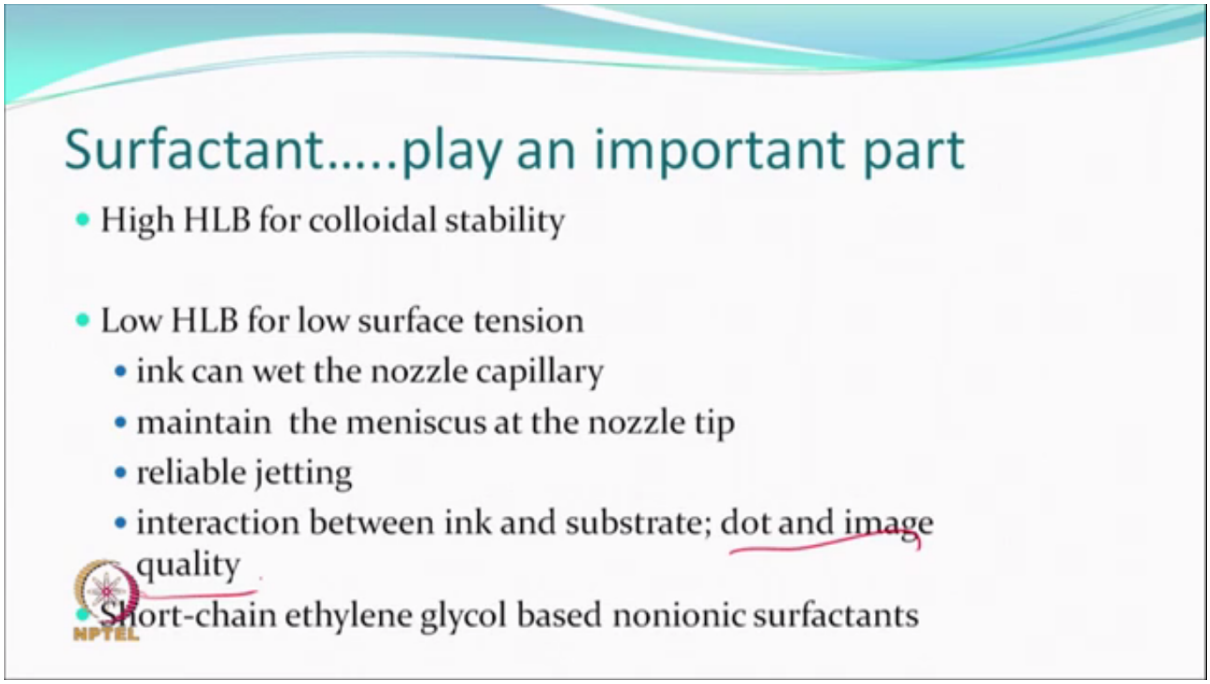

So as we believe that here also some short-chain ethylene glycol based nonionic surfactants may be optimized for their properties from the term with, with respect to the colloidal stability, and the wetting and other jetting reliability of the ink.

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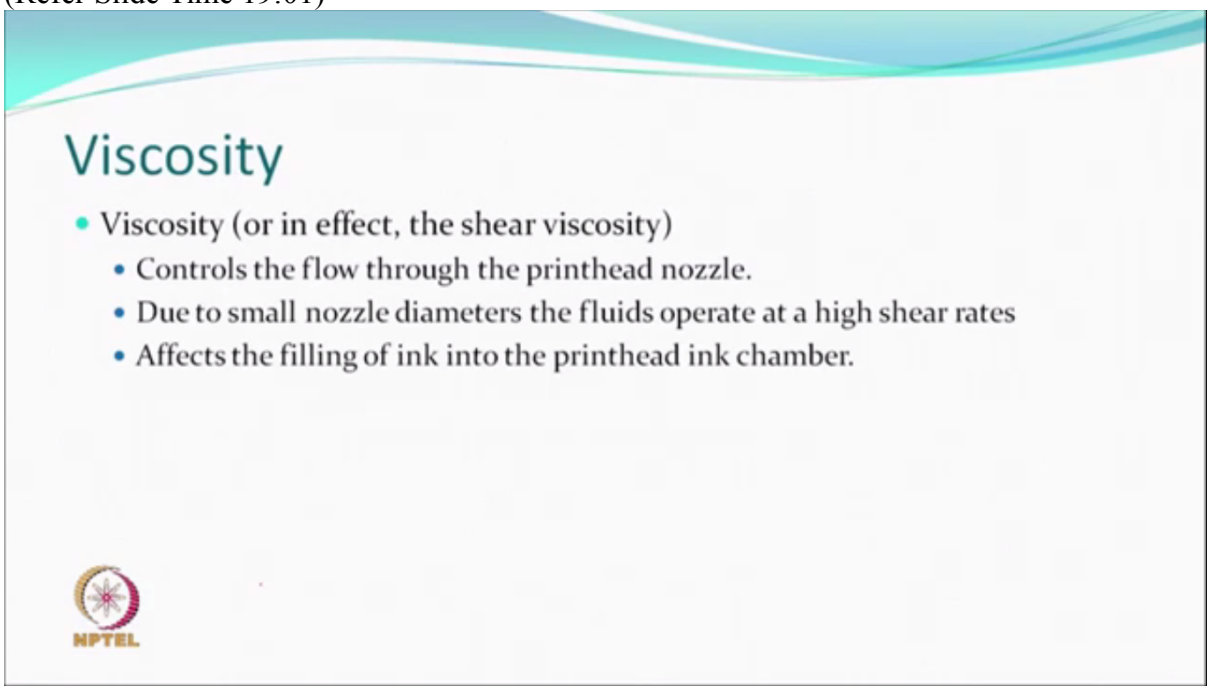

Viscosity we just talked about before also. In effect, we are talking about the shear viscosity. So it controls the flow through the printhead nozzle. Due to small nozzle diameters, you can understand so many of the nozzles are there in very small area. The fluid actually while it is coming out operates at a higher shear rates.

It affects the filling of the ink into the printhead also. So when it is coming out, it should have a high shear rate, but when it is stationary, then its behavior is different. So the behavior of

the ink whether it is going to be shear thinning, shear thickening, this is what will be important for us to learn.

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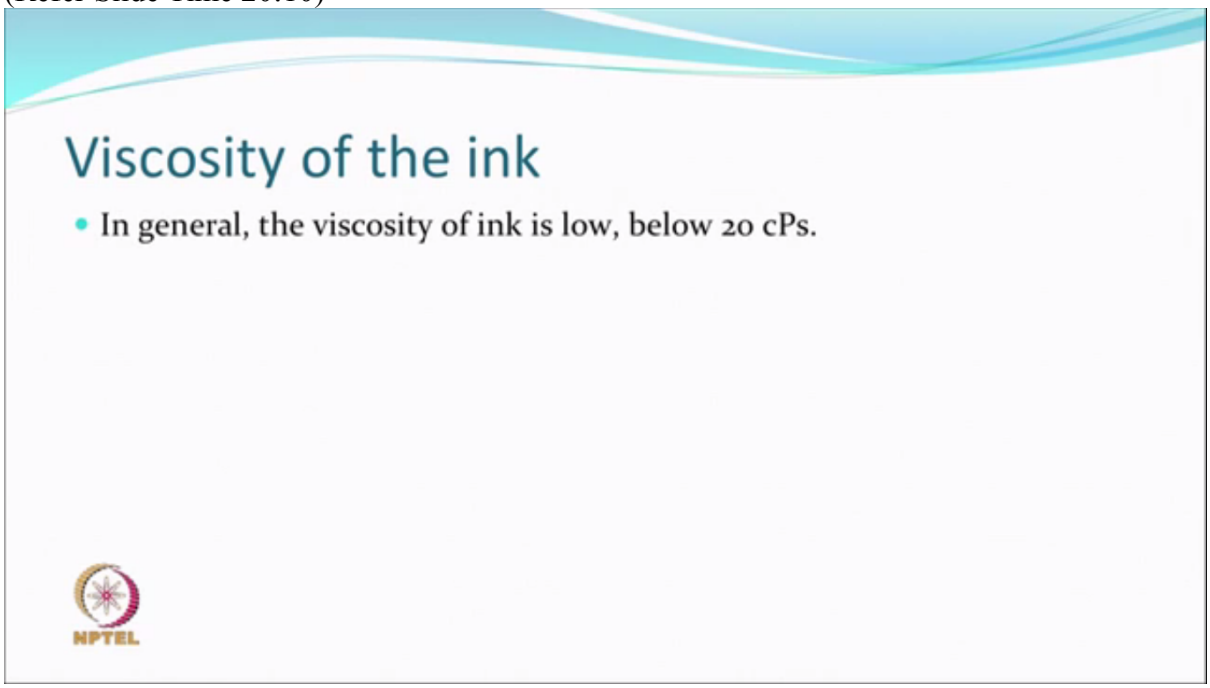

So we again revise that the viscosity is low generally around 20 cps. We also understand if viscosity is too high, clogging and other things can happen, and we also understood that even at this low viscosity, the rheology profile cannot be ignored and it is controlled with relatively high molecular weight water-soluble polymers.

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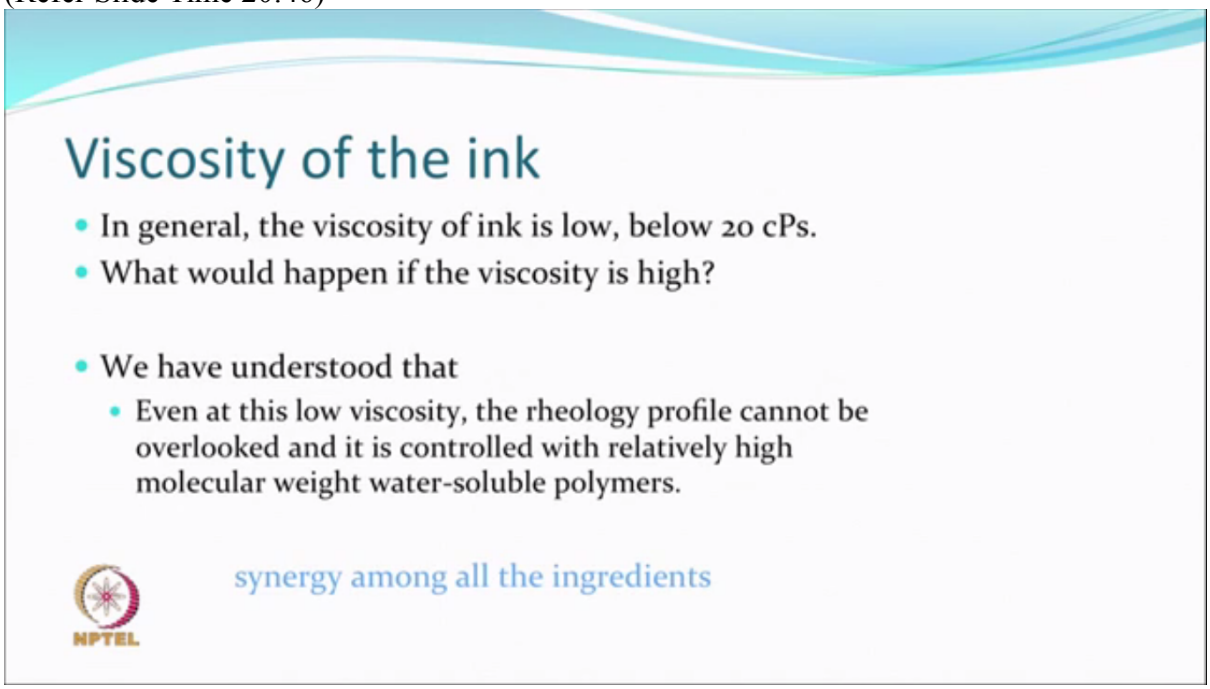

When so many things have to be added, people will have to worry about the synergy between all the ingredients that you will be adding. So one thing is clear, it is not just a simple ink

which has only pigment or dye. There are many other ingredients which are going to be looking at the rheology, the viscosity, the surface tension of the ink.

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So do we require shear thinning? Yes, we do require shear thinning because the time taken for even the smallest droplet to come out of the nozzle is very, very small and therefore rate is very high. And so if it is not there, there will be back pressure develop. The actuators may not work very nicely. They may get affected adversely. Their functions may be really affected badly and so we do require shear thinning behavior of the inks for printing.

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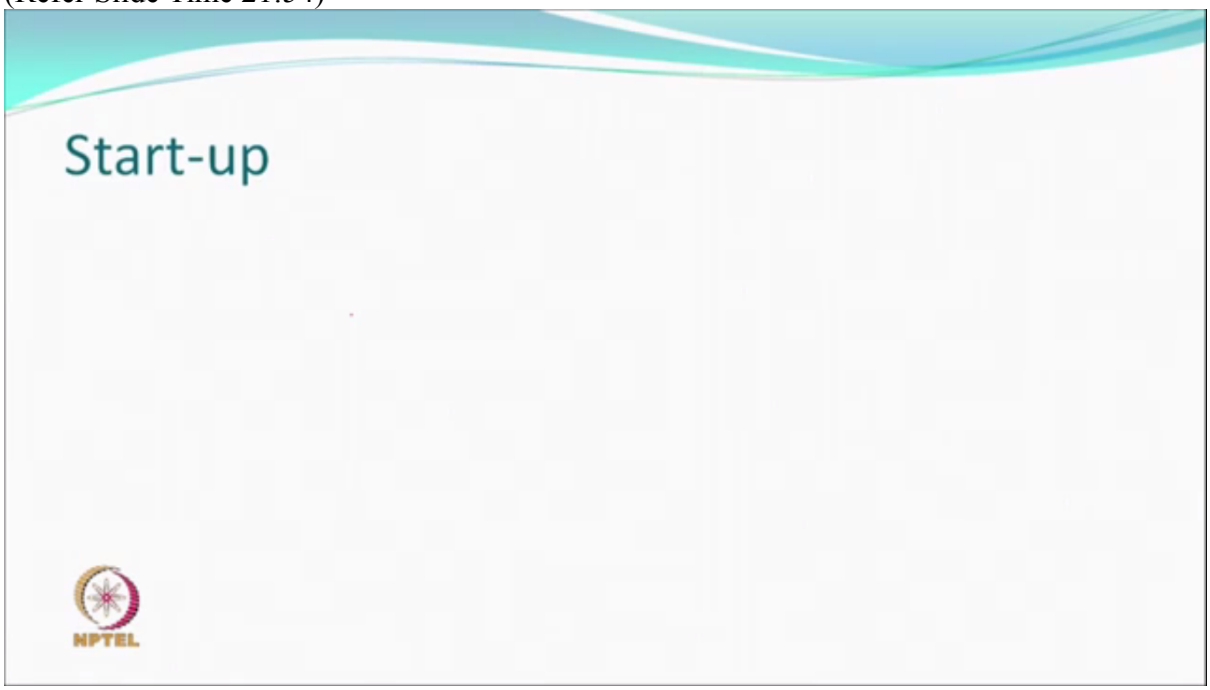

Start-up. That is when the machine is started, how much time does it take? Zero time to start printing or you think there may be some more time required before good print start appearing. This is an important thing. So that that is what people do that the printhead goes to the ends of the carriageway where it is called priming. It stays there. if anything is sticking, it may be cleaned also at that station before a printing start-up, but therefore start-up is an important thing.

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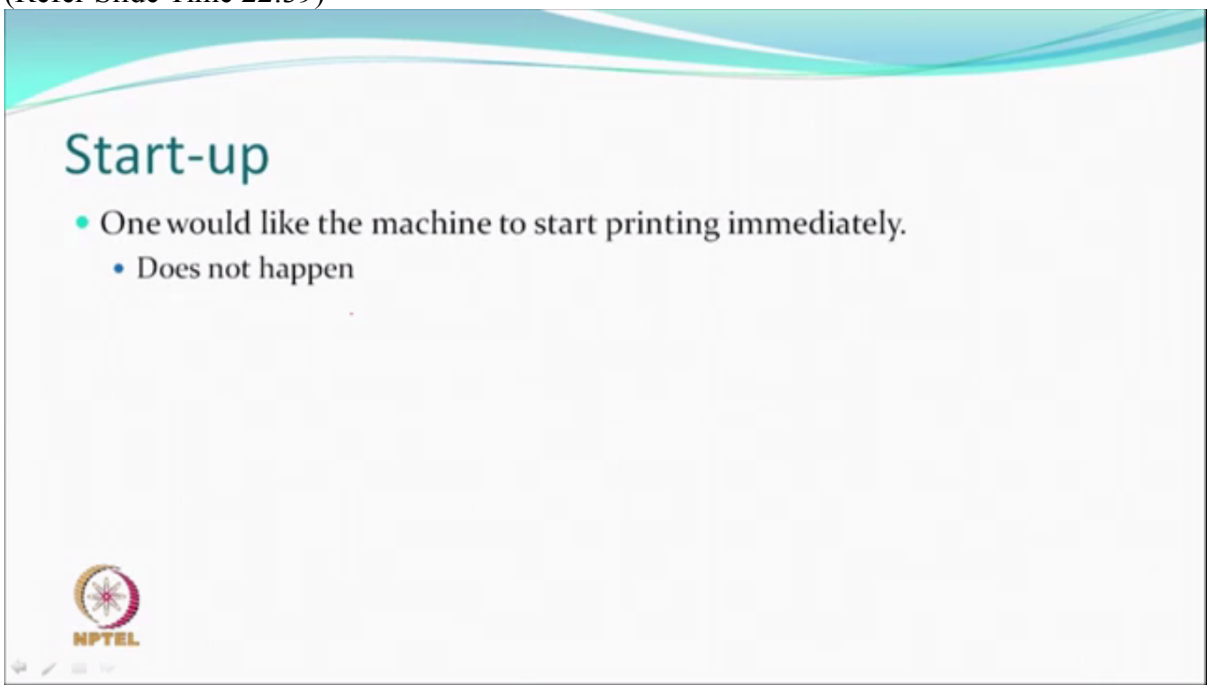

One would like, obviously, the machine to start printing immediately. It doesn't happen. So there may be something. So there is a time that requires and that is sometimes known as the latency.

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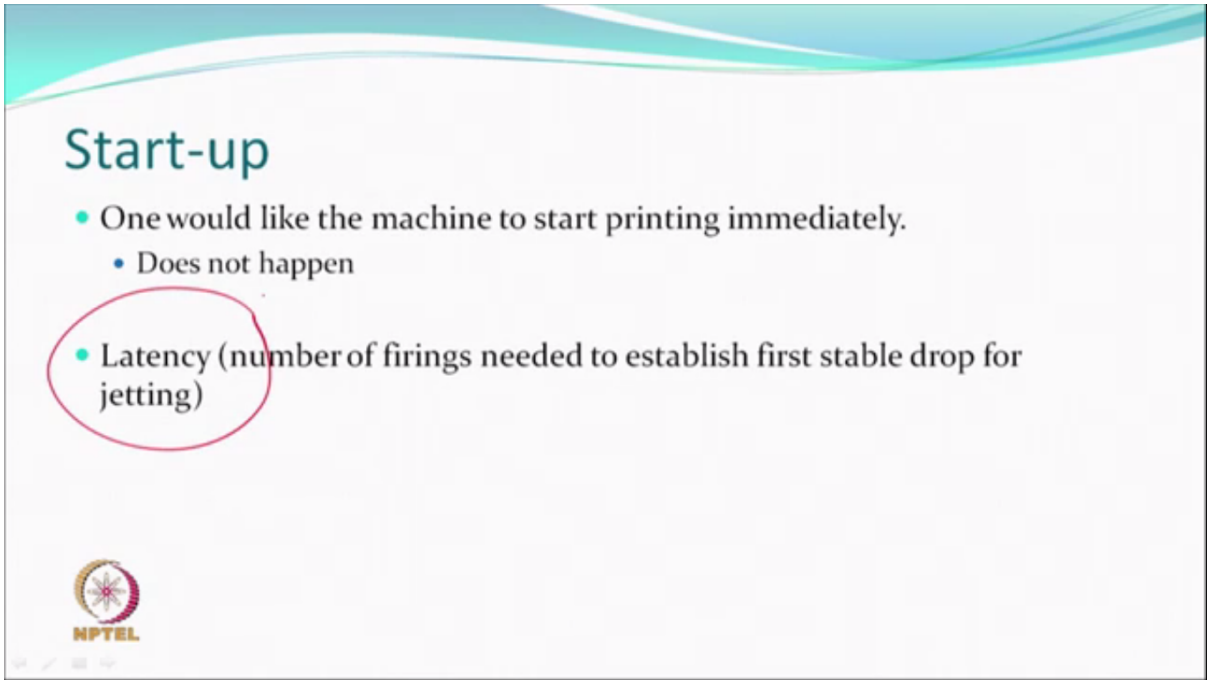

Latency is basically the number of firings needed to establish the first stable drop for jetting. If something is sticking somewhere, some portion is dried up, the holes are not really clean, so it takes how many firings it is required before everything smooth comes out is called latency and this is what sometimes known as start-up issues.

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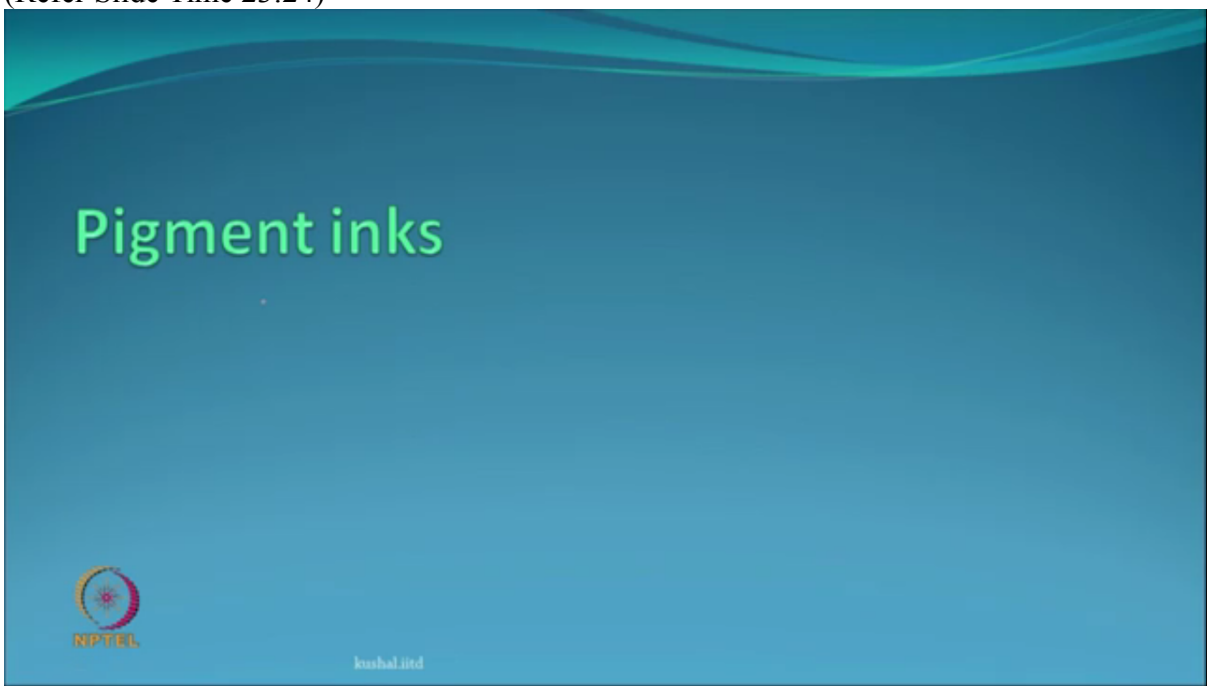

So among various ink types that we use, today, we will look at pigment inks. Pigment, obviously, is a colorant, which as we understand does not have any affinity. We should not say any affinity. There will be some affinity for everything. Everything have -- can make (inaudible 23:55) force and so on and so forth, but when we talk about affinity, we mean either it makes covalent bonds or it makes ionic bonds or makes hydrogen bonds, and

specifically those things are not there and so advantage obviously is there. Advantage is that it can the -- if it can be fixed, it can be fixed to any substrate.

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So this is the prime advantage we can think of. All substrates can be printed. Even the blends of various fibers can be printed. And if a process becomes simpler and which means print dry and probably maybe cure also so that drying may be at a temperature which is higher enough to ensure that there is a film which is been cured and fixed onto the substrate.

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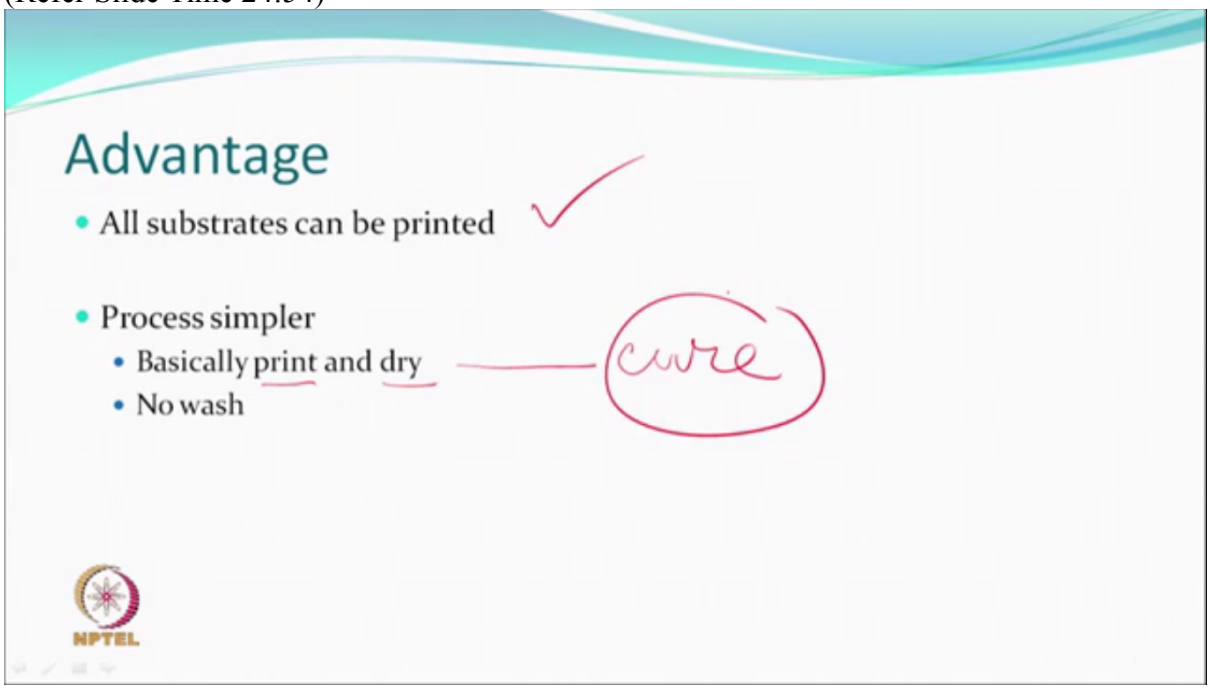

I'm sure you understand that because as we said pigment does not have any affinity, therefore, something is going to bind it and that's because the binder which makes a film. But good thing is that you don't need to wash because everything is fixed.

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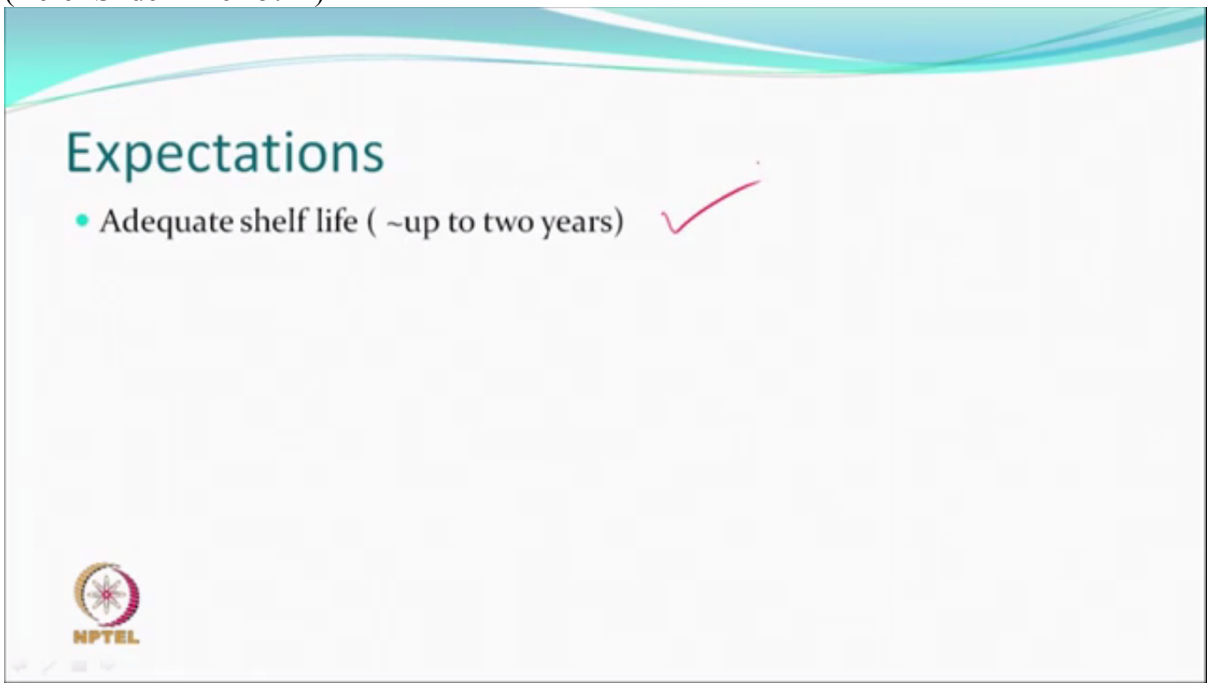

Of course, we have lot of expectations whenever we look at ink also pigment ink. One of the expectations is that it should last quite a lot. Think of the print paste that we were making, we expected it to last for a day; maybe two, three days. The stock thickening may be a little more than four, five days; maybe a week. That's the maximum you can think of, but the shelf life of the inks is expected to be up to two years. That means everything, all the ingredients, which we just discussed before, must remain functional and keep doing their functions.

We expect low viscosity and reliable jetting definitely.

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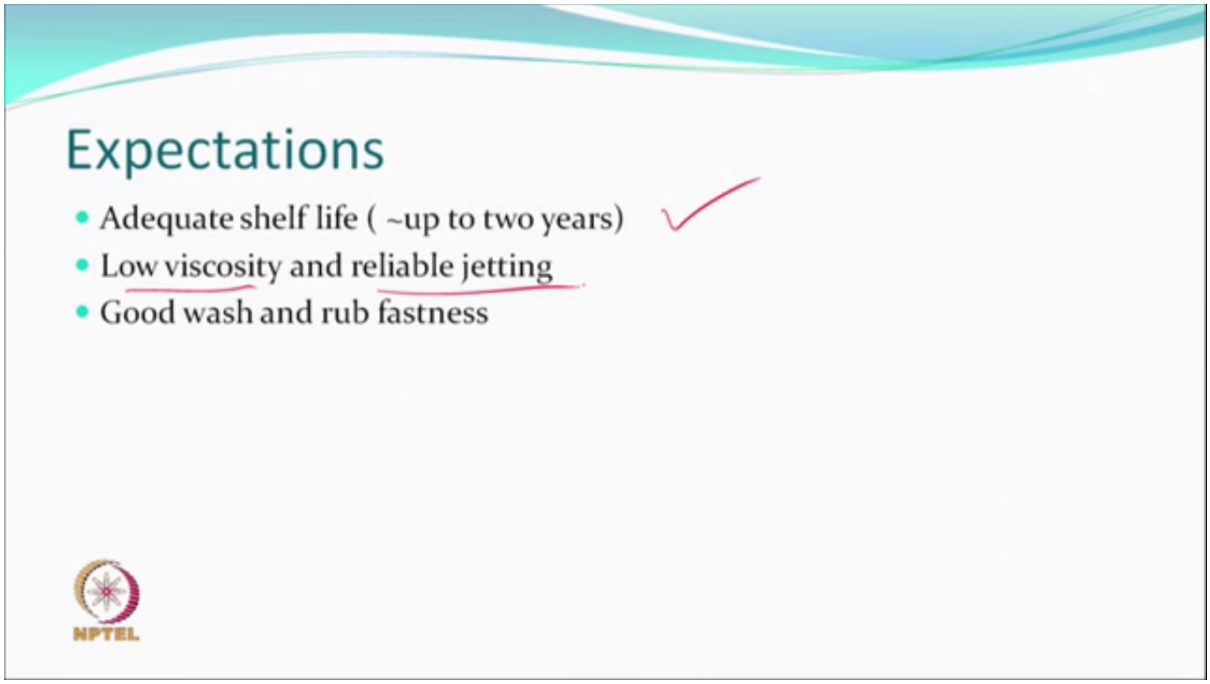

Now we are talking about remember pigment inks. Pigment inks, of course, we will wish good wash and rub fastness. Rub has come here because now we are looking at a textile substrate. You have some pigments and then there is a film, which is holding, so expect either wet rubbing or dry rubbing. If the film breaks, then things can be different.

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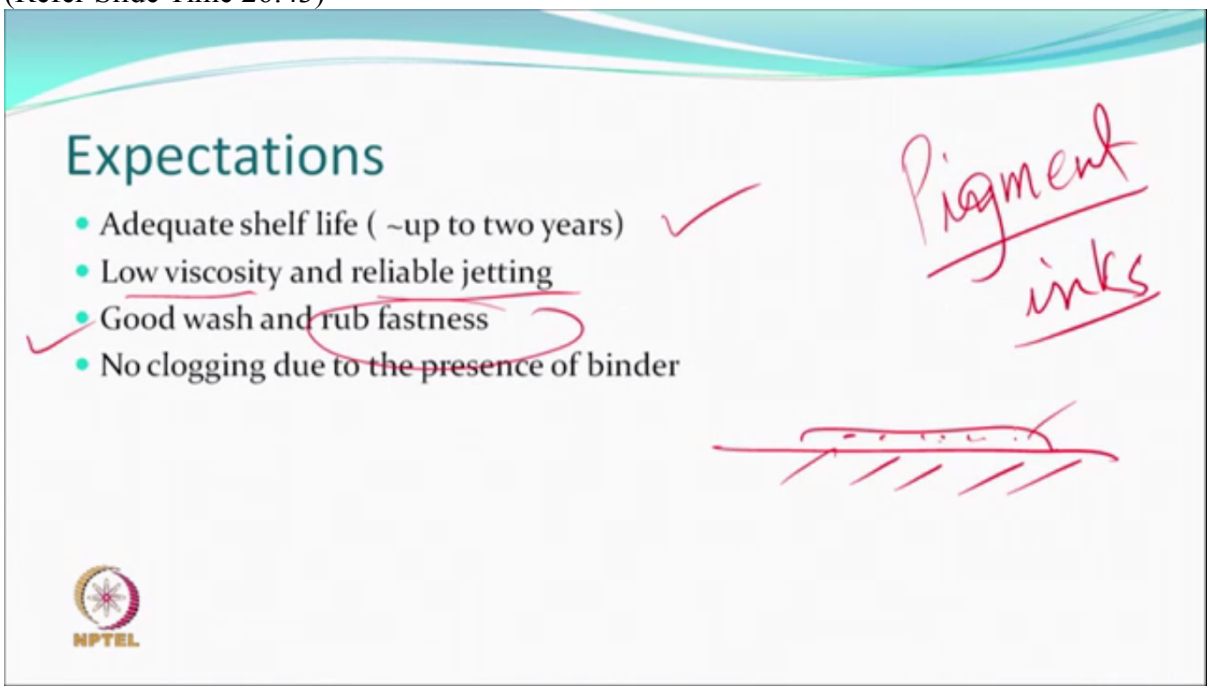

Now the binder, where is it? Is it inside the ink or outside the ink? Normally, people would prefer the binder to be inside in the ink itself, and so if this is a film forming substance, then it may result in some clogging here and there, but we expect it should not.

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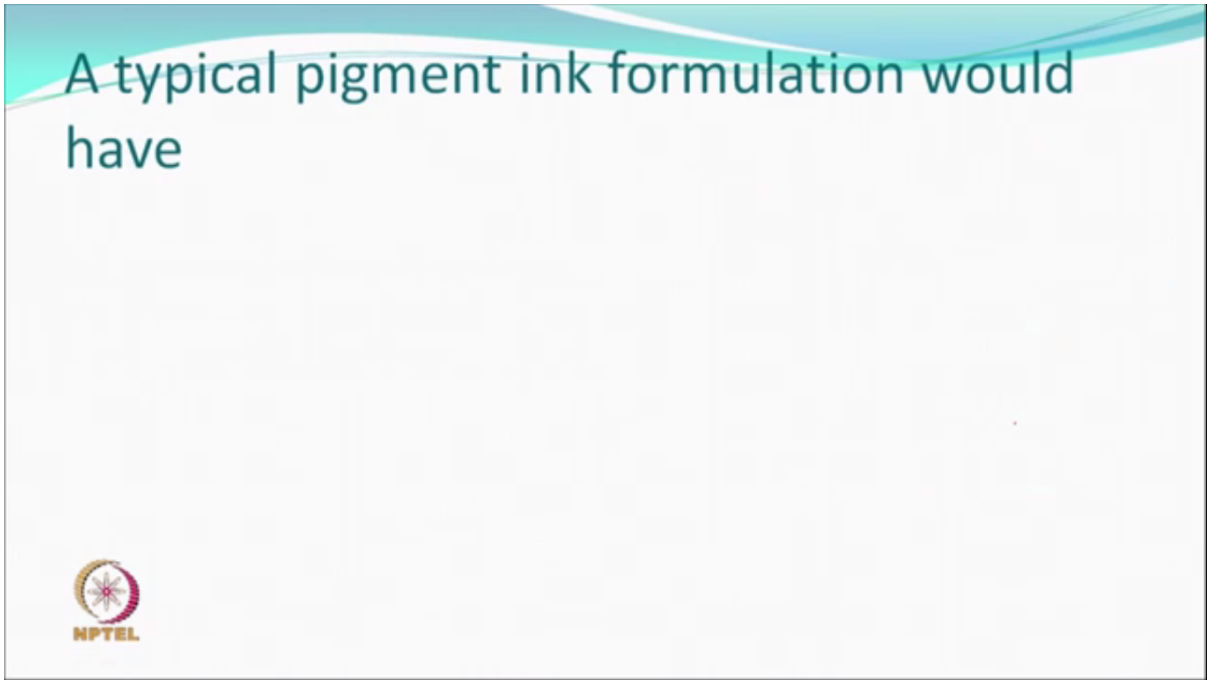

So with those expectations and the something which we learned before touching the pigment ink, so the formulation of a pigment ink is going to be quite a juxtaposition of various kinds of chemicals based on the requirements. Of course, there will be pigment and pigment is not generally water-soluble and therefore this will be a dispersion.

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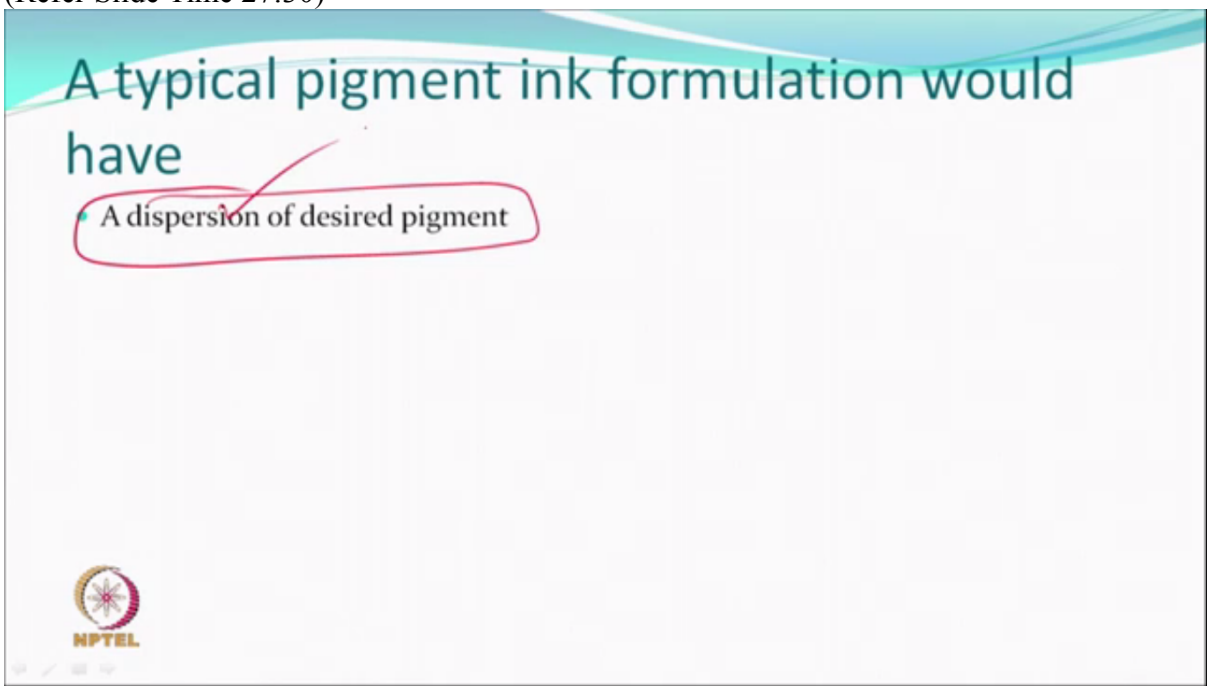

So this will be a dispersion. So that, of course, will be part of any pigment ink, but the most important is pigment will have a binder because this is the one which is keeping the pigment inside.

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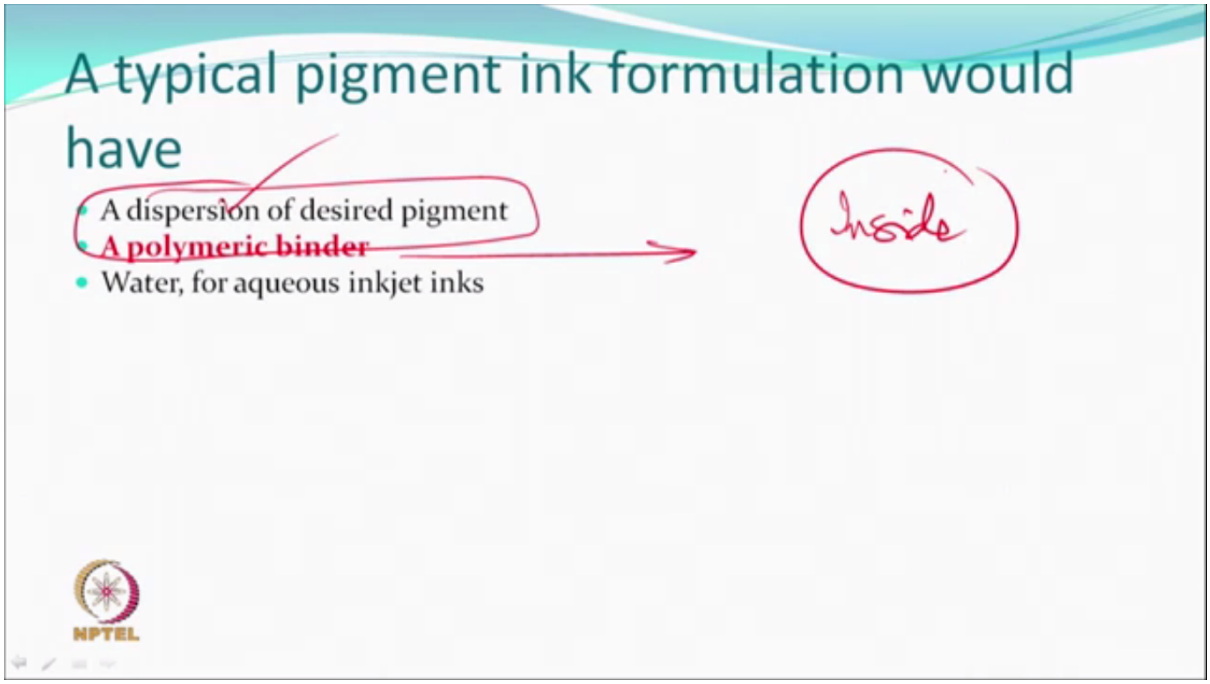

Water, we generally prefer aqueous ink. So, therefore, there is a dispersion of the thing and there is a polymeric binder and so some water aqueous systems.

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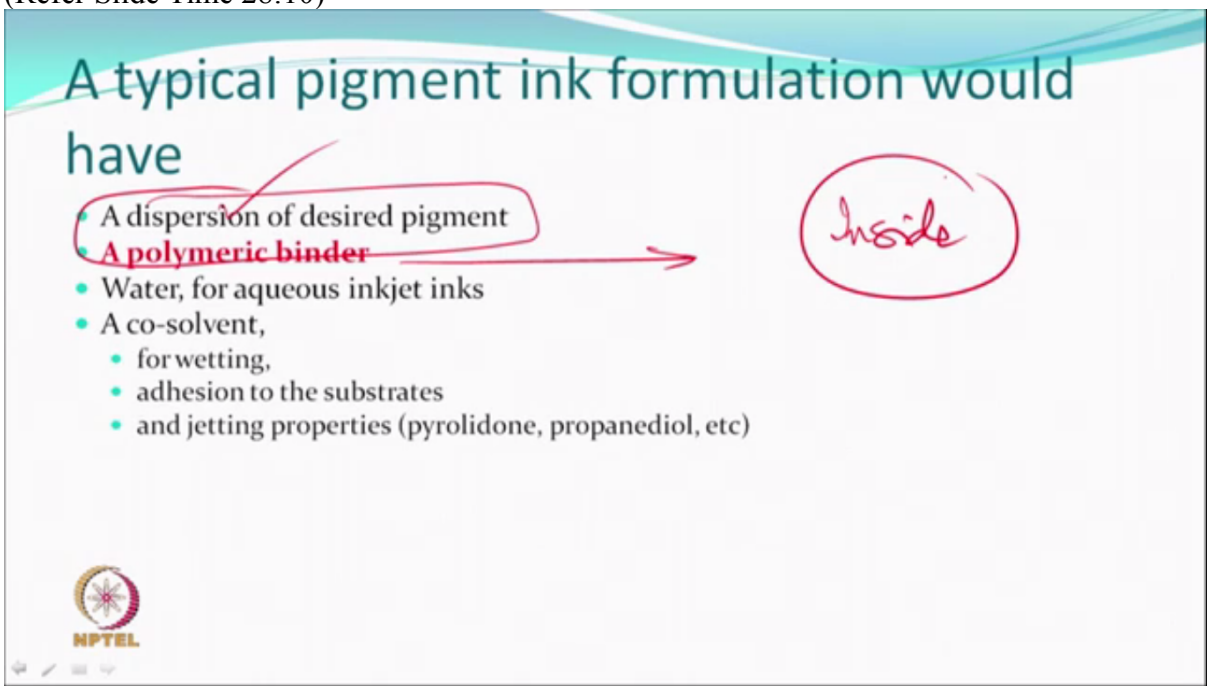

A co-solvent so that the surface tension and wetting properties are modified to suit the requirement. It will have the purpose of wetting, adhesion to the substrate and good jetting. Some of the examples which compound which can be used are pyrolidones or propanediols etc.

Surfactant, which obviously modifies the surface tension, and humectants because sometimes you, when we are drying, all the reactions, it should not become such that everything is too dry. So a bit of a moisture may be advisable. So after drying particularly.

Antifoaming agent because whenever it is in the chamber, going to be at a very high frequency. This is going to be impacted and so we would not want any foam. So antifoaming agent may be a part of it.

Viscosity controlling agent, as we said a bit of a polymer could be added so that viscosity is controlled.

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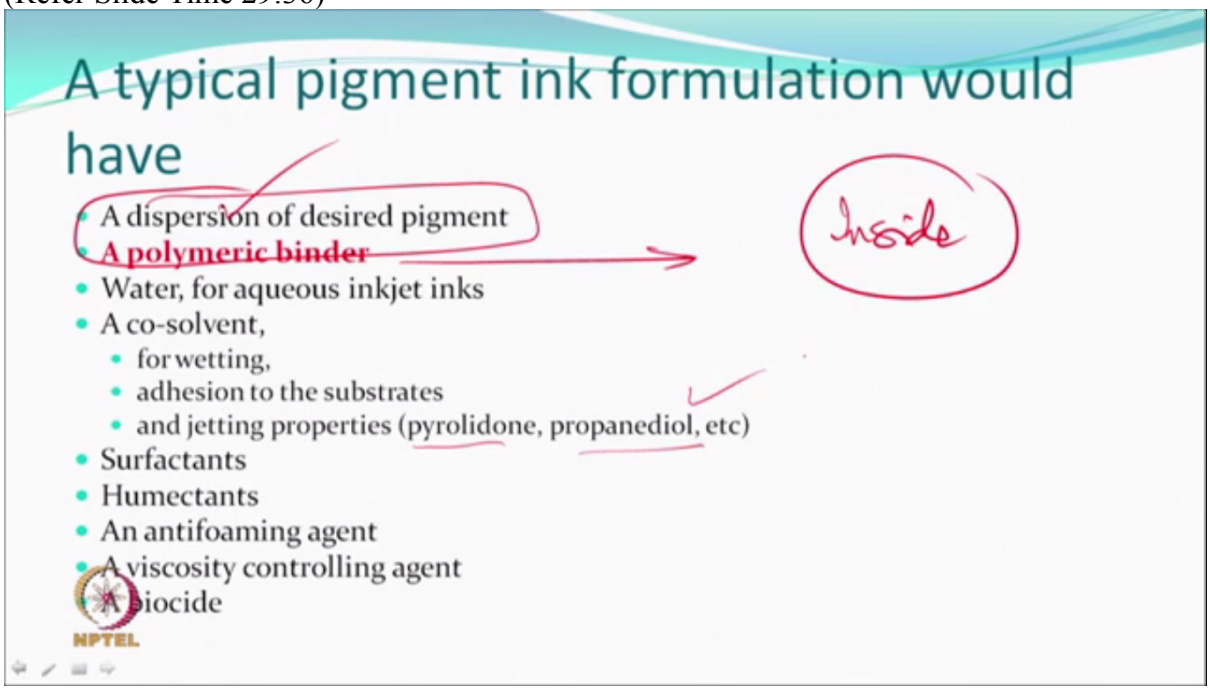

And a biocide because if you're looking at something which has to stay for years together so we expect that no change should take place. Biodegradation or biological growth should not be there. Otherwise, lot of other things happen, which obviously are not good for anyone.

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So let's say pigment dispersion.

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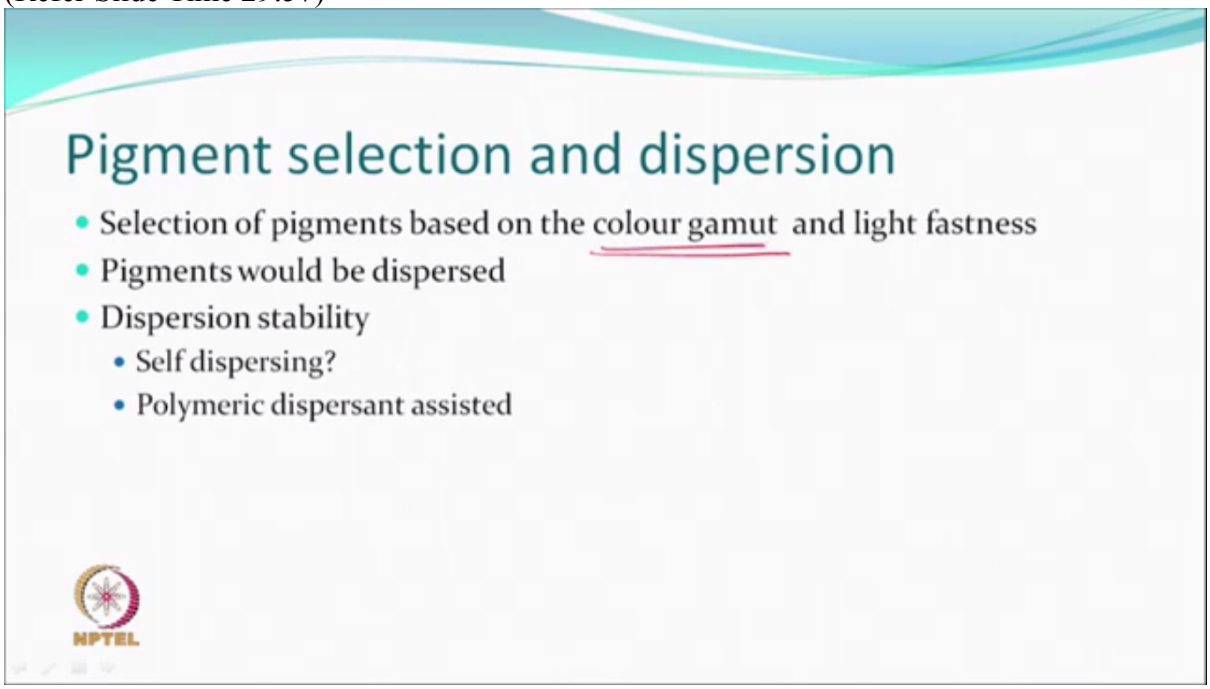

So what pigment will depend on the color gamut. I mean, normally, we expect four colors should work, but in case required more could be used. White is one other than the CYMK. We may have white. Of course, we expect these to be having high light fastness.

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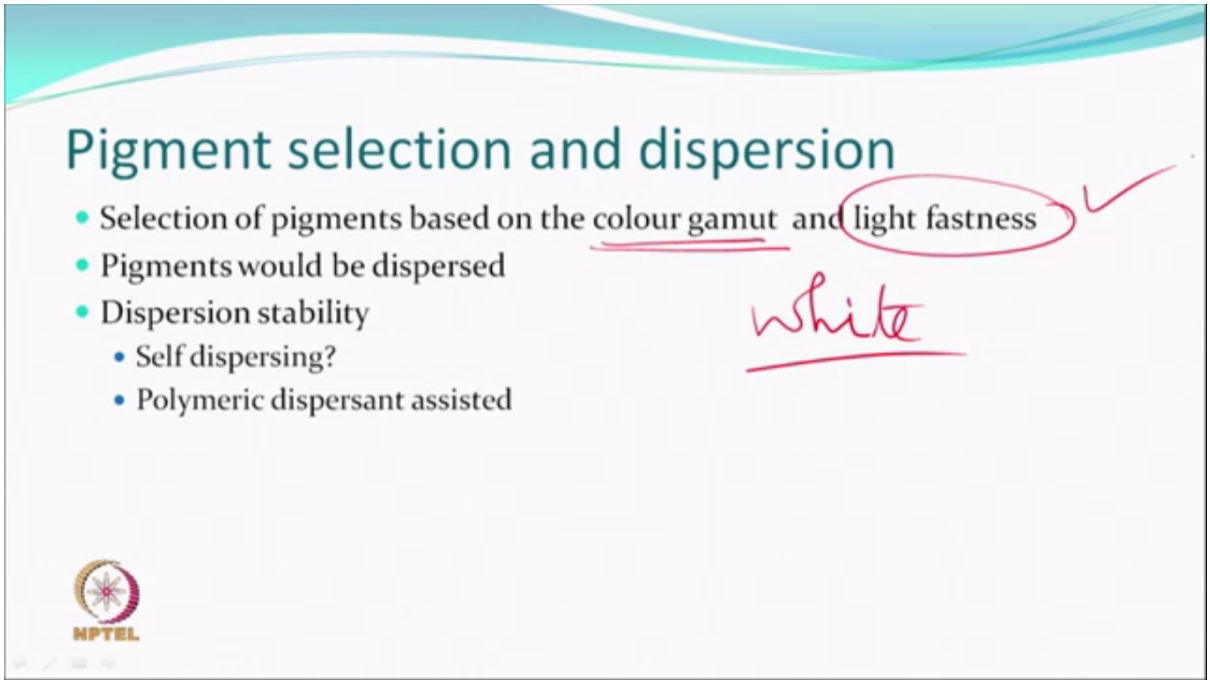

Pigments would be dispersed obviously because they are not soluble in water and dispersion stability is what is going to determine the shelf-life. If the particle size is very, very small, they could be self dispersing. Otherwise, you may have to use a polymer-based dispersant, which can assist the good dispersion happening.

Now what's the particle size we are looking at?

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Approximately, zero five, .05 to 0.15 micron size. So it's a small size so that should be able to come out of the nozzle without any hindrance.

Distribution of particle size, the particle size distribution we're talking about. So you can have a very sharp narrow distribution or you can have a broad distribution.

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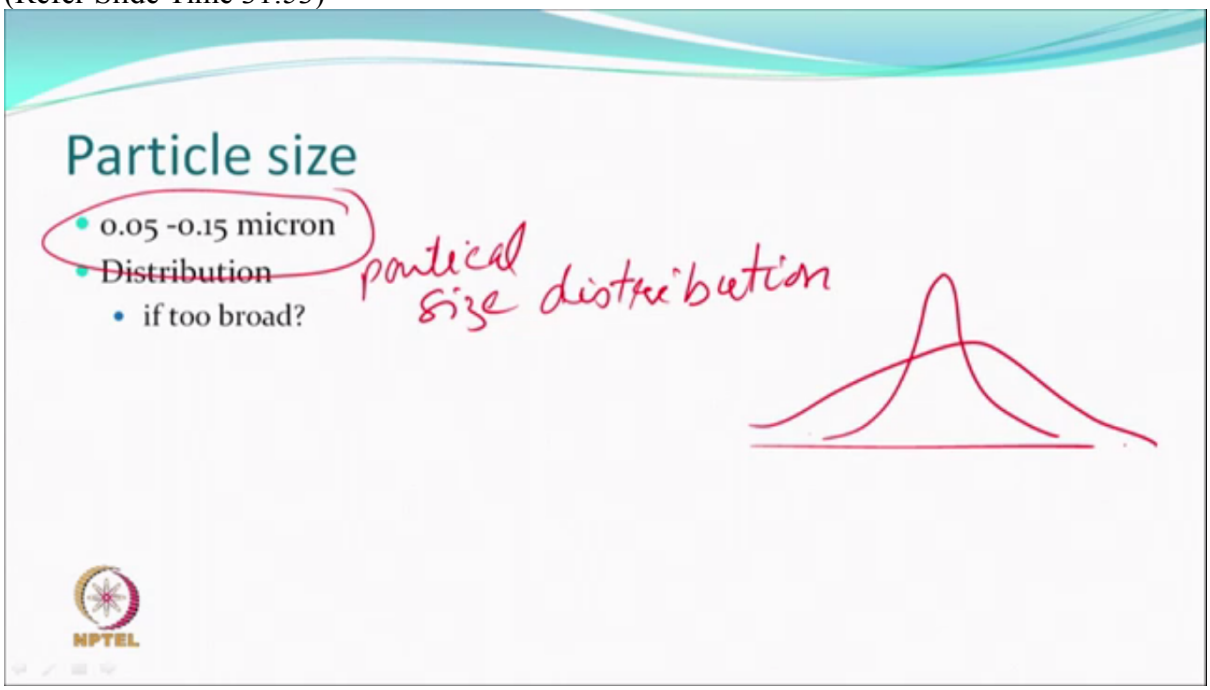

So, obviously, one would like to have as narrow a distribution as possible, but it's always a challenge. It's not easy to do, but the milling is the operation which is done so that the particle size is brought down to a certain range.

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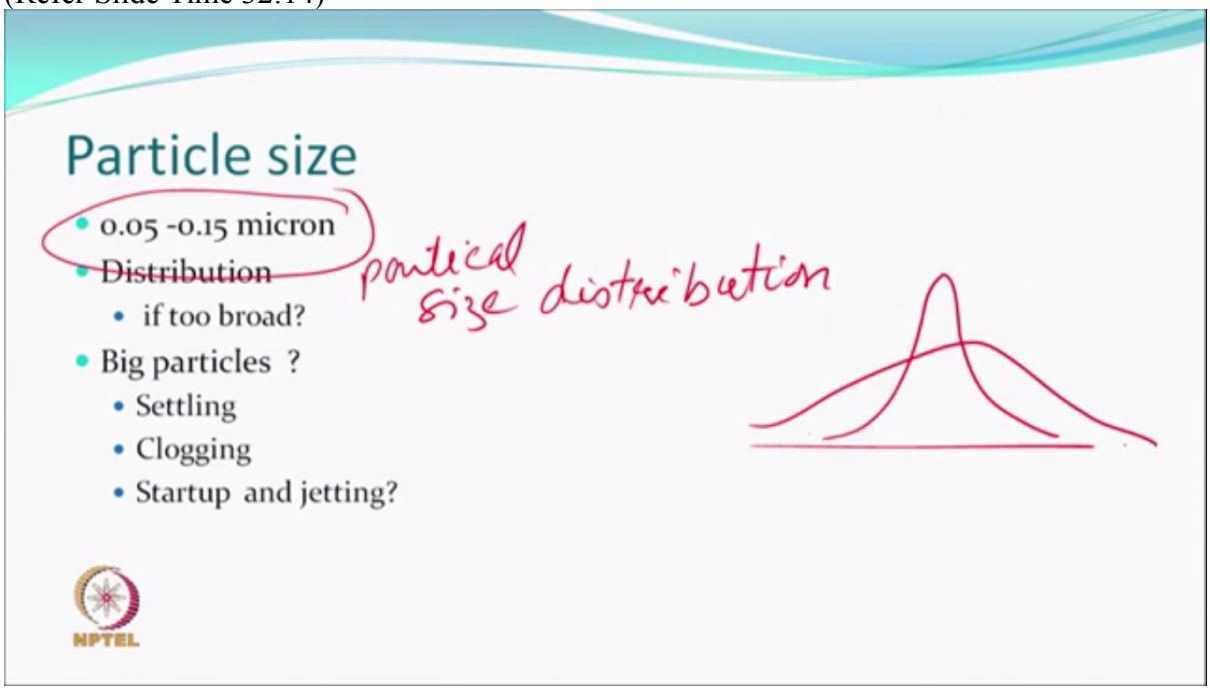

If it is too broad, obviously, it's not good because there will be large number of particles or there will be relatively large number of particles, which will have very large size. So big particles will have a problem that because of size they may have effect on settling down by the gravity. They would obviously very naturally may be the ones who are responsible for

clogging. The finer ones keep moving out. The larger ones may actually get stuck and that would lead to start-up and jetting problem.

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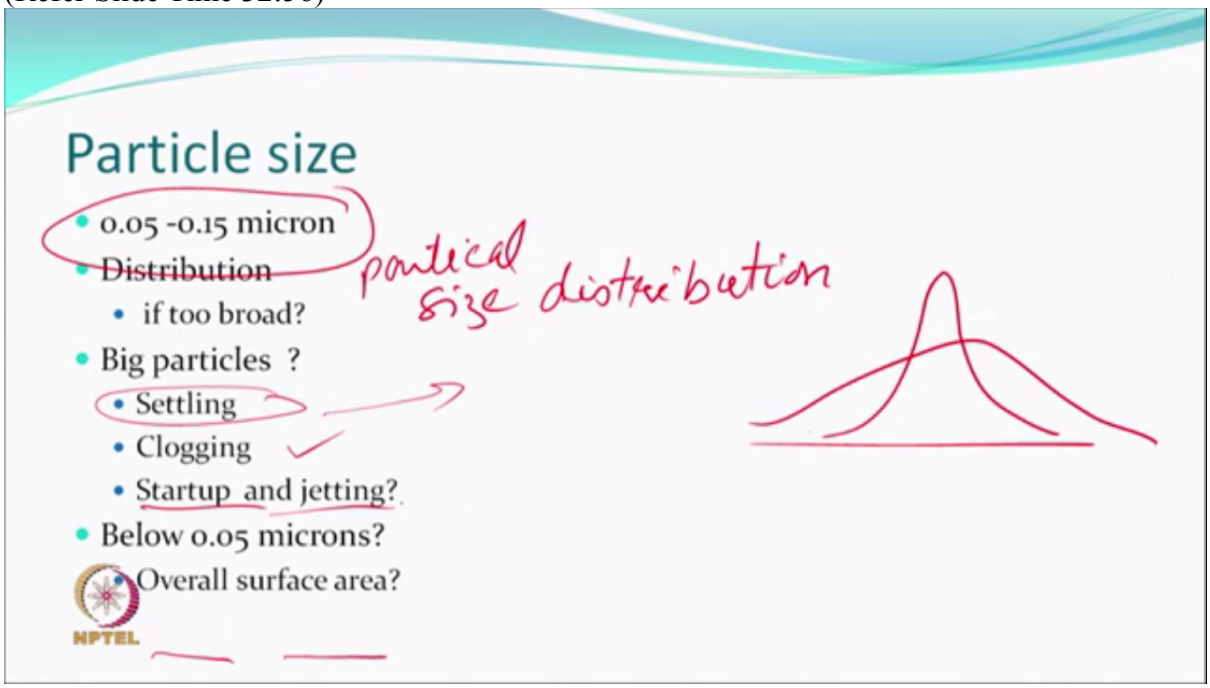

If the size is very low below 0.5 microns, so what happens? Very, very small size, very, very large surface area, overall surface area very large. Keeping them dispersed is a challenge. Very small particles will have a tendency to agglomerate and so there's the approximate range is 0.05 to 0.15 micron.

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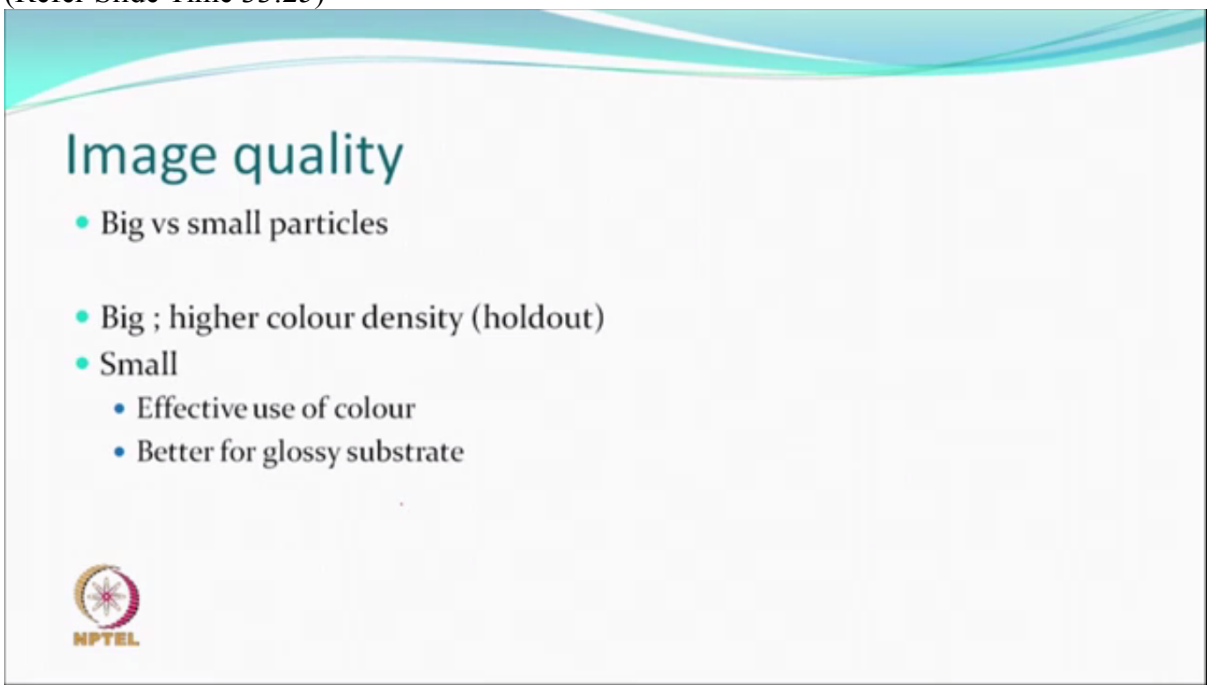

Image quality. Does it get affected by the size of particles? So it is approximately understood that higher color density or a holdout sometimes called, the big particles are responsible for

that. The smaller particles affect actually lead to an effective use of color and generally for a glossy substrate, they are used as a smaller particle, but most -- the best reason why a particle size should be have a certain value would basically depend on more on jettability rather than only looking at the color density and so on and so forth.

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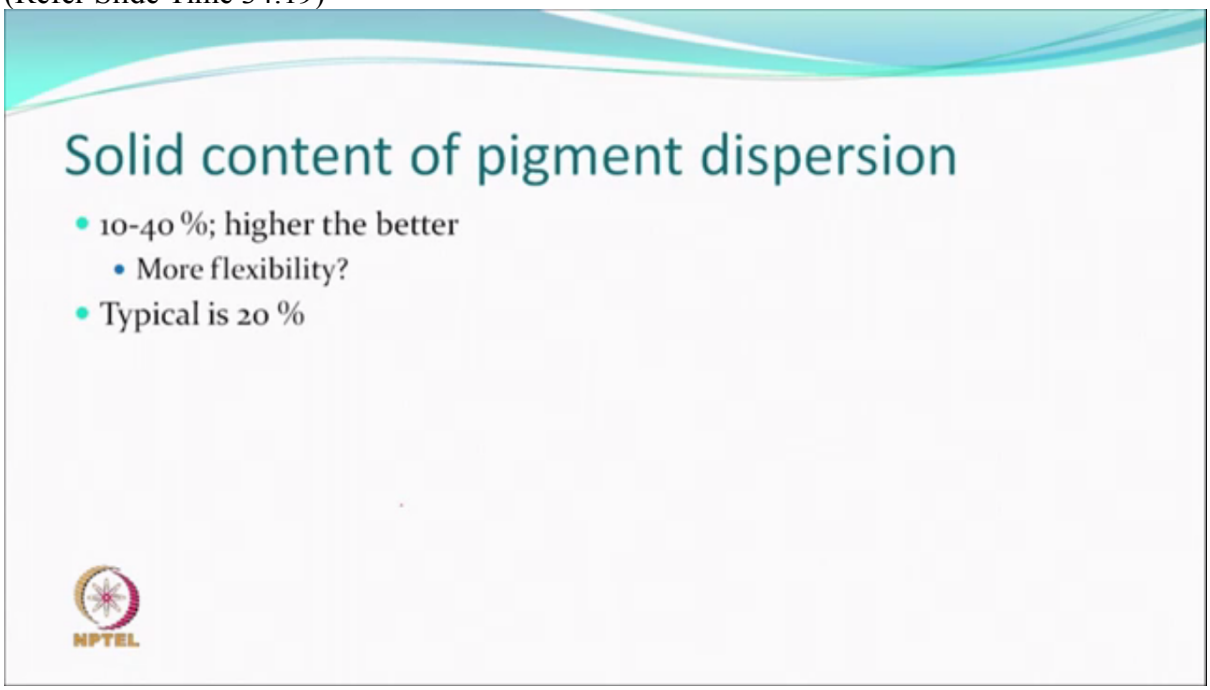

Now the dispersion, how much should be the solid content of the pigment dispersion? I mean, one can have dispersions percentage varying from 10 to 40%. Higher is the solid content, better for transport and this dispersion finally is going to be mixed with solvents, co-solvents, surfactants, viscosity modifiers. It gives you more flexibility because the concentration is going to be only diluted. Well, typically, you may get surfactants with the dispersions and solid content of about 20% or so.

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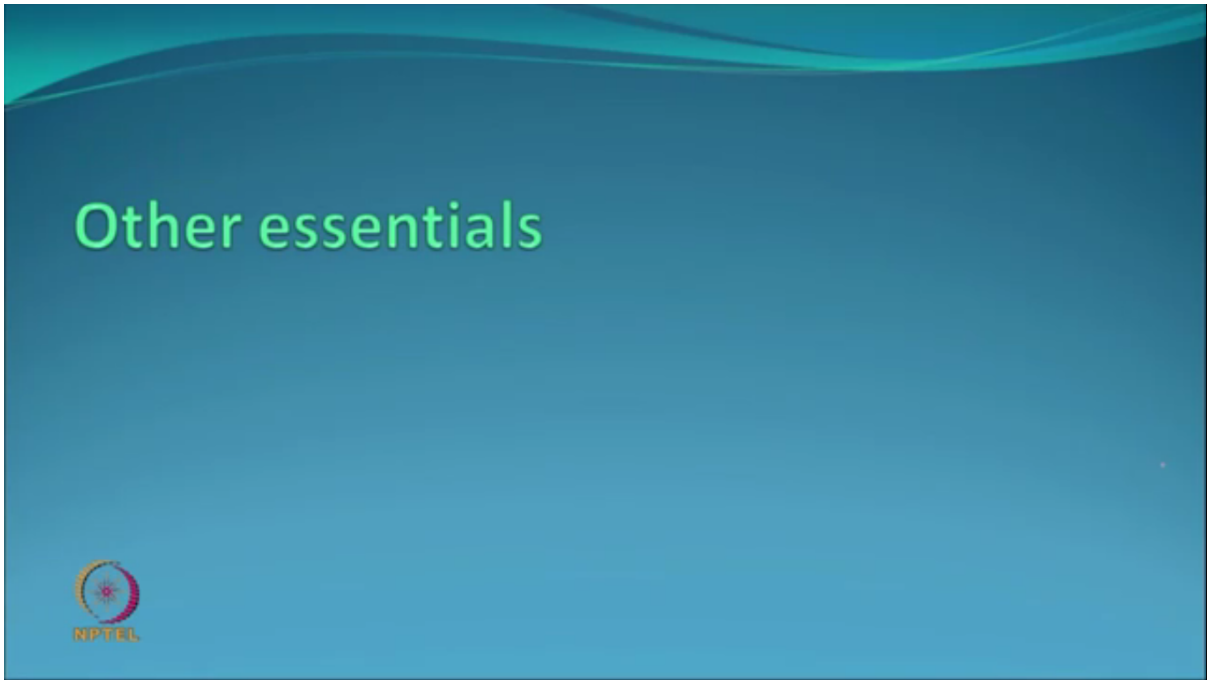

Other essential things which must be part of the ink is the binder. It is essential. Without the binder, there is no pigment ink printing.

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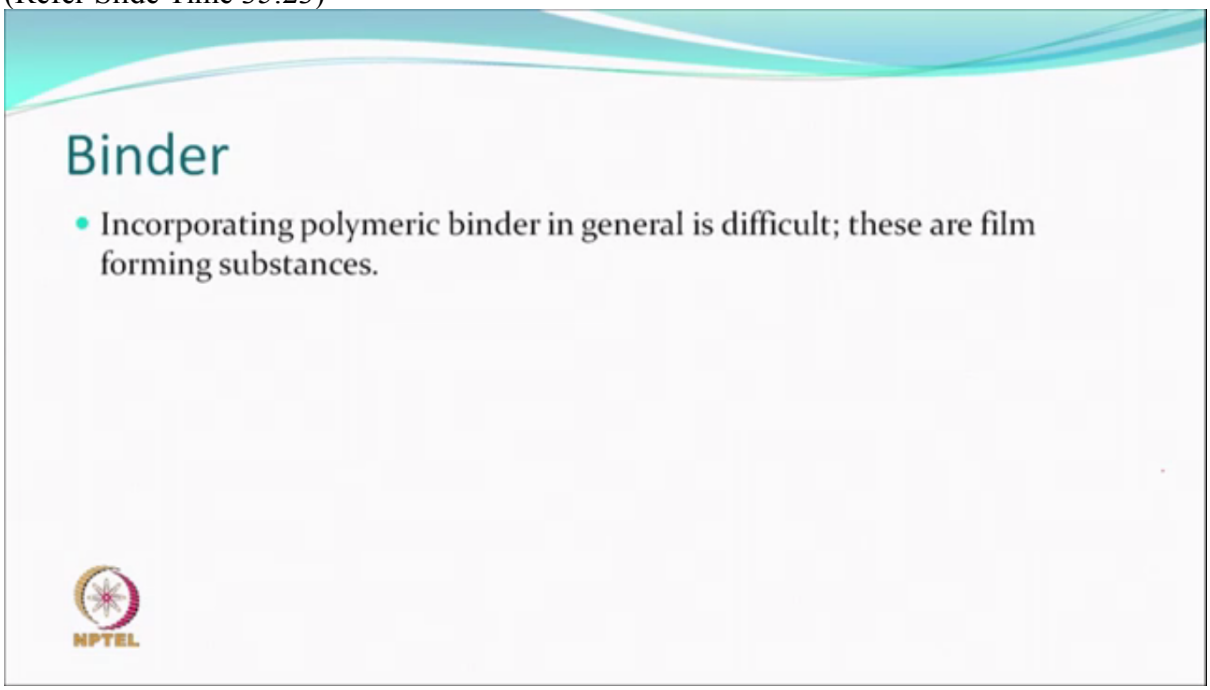

So incorporate a binder in the film. These are film forming things, film forming substances, and therefore for a long time people thought let the binder not be there in the think because it can have gelling and other effects, but then that would mean that your pretreatment or a post-treatment will be different. When do you add a binder? So the binder had to be in the ink. If binder is not in the ink, what do we do? We apply the binder to the whole fabric and then do printing or we do the printing and then apply a binder on the top. That binder will be all over the fabric where the design is not there. If the binder is in the ink, then the binder will bind the pigment only in the areas where there is a design. When there is no design, there is no

binder. So it is logical that you want the binder to be in the ink itself, but it obviously has some challenges.

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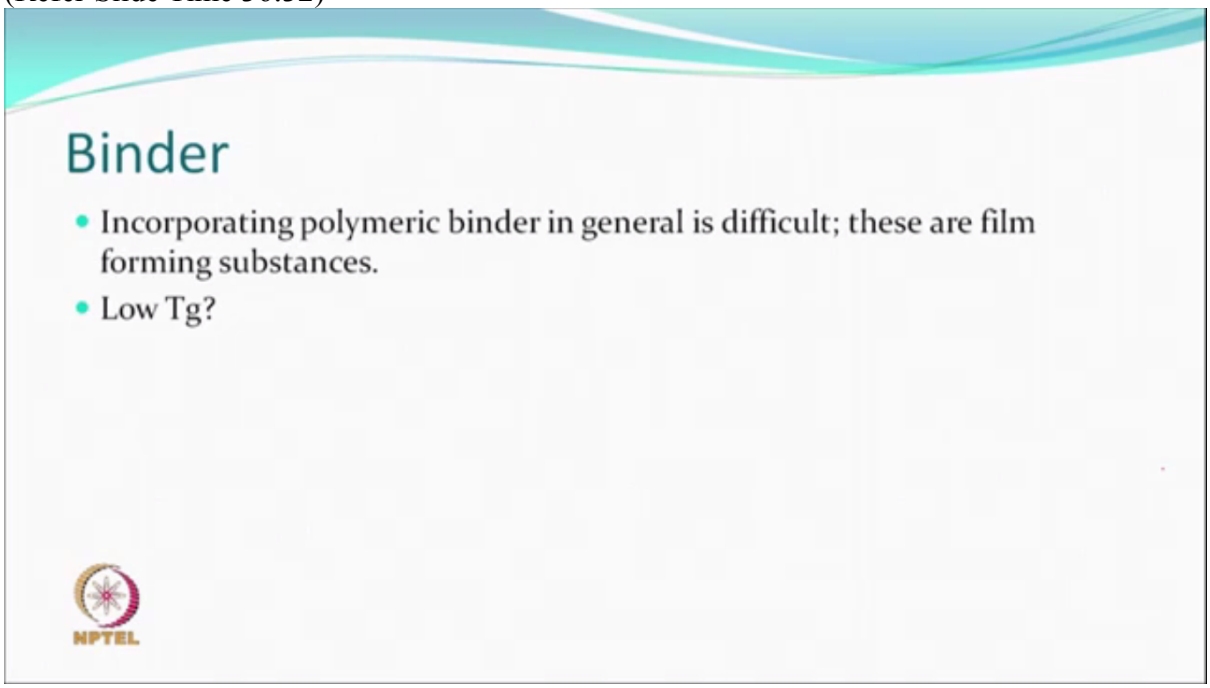

The polymer should have low glass transition temperature. Whenever you make any film or put any film, laminate anything on top of a surface, the fabric, rigidity increases. Flexibility changes and you don't want that. So how do you help that? So low glass transition temperature, that's what helped, helps the cause.

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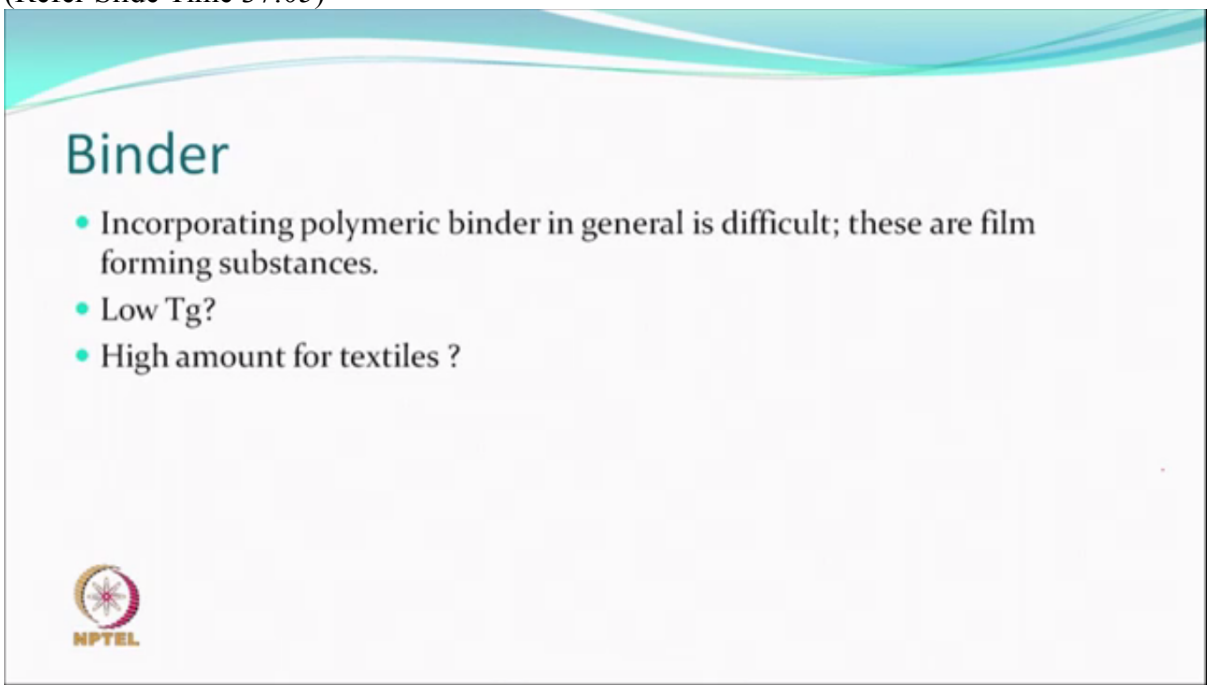

For textile it is required more because the textiles, the printed textile will have to washed many times over. If it was just a pigment printing on a surface which is not to be washed like

a paper or a wall, then life will be very different or a panel, but textiles have to be washed and therefore, generally, higher amounts are also required.

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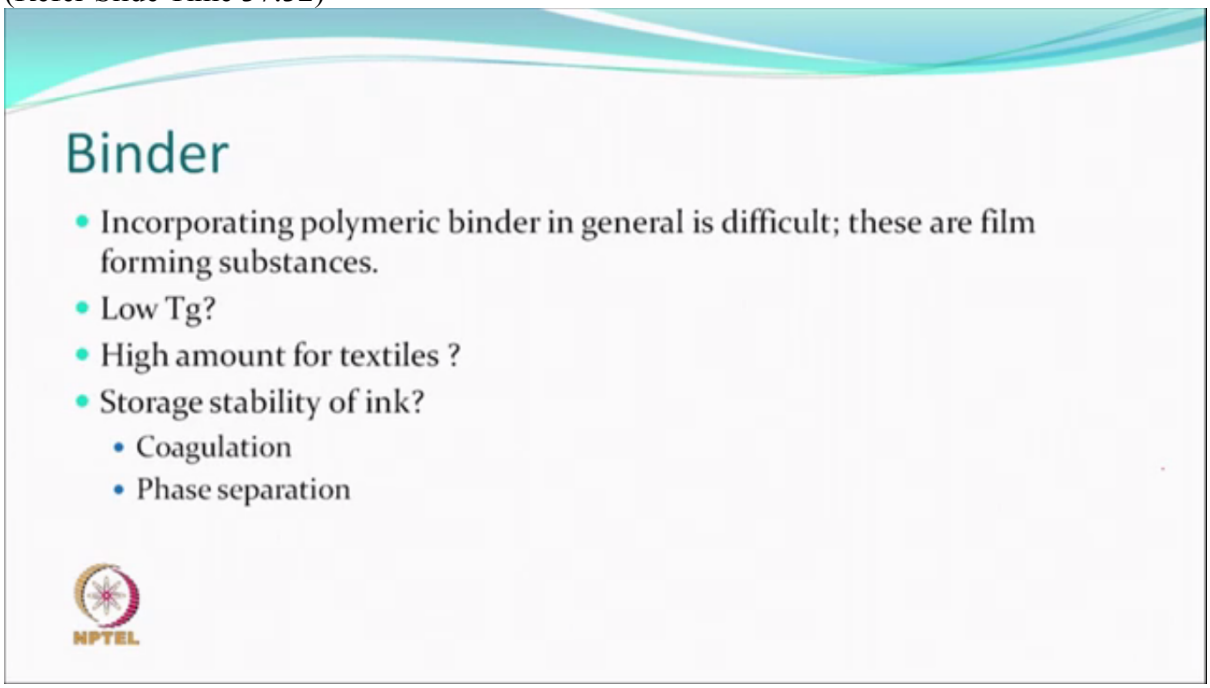

Storage stability of the ink. So one may have coagulation as we said and there can be phase separation between things which are very soluble in water versus which are less soluble in water. All that can cause a problem and binders, therefore, prove to be more difficult ingredient.

If things are not right, jetting may not be reliable. As I said if the binder which is a film forming substance can make some gels anywhere, then it can get stuck around inside or in the nozzle or completely block it.

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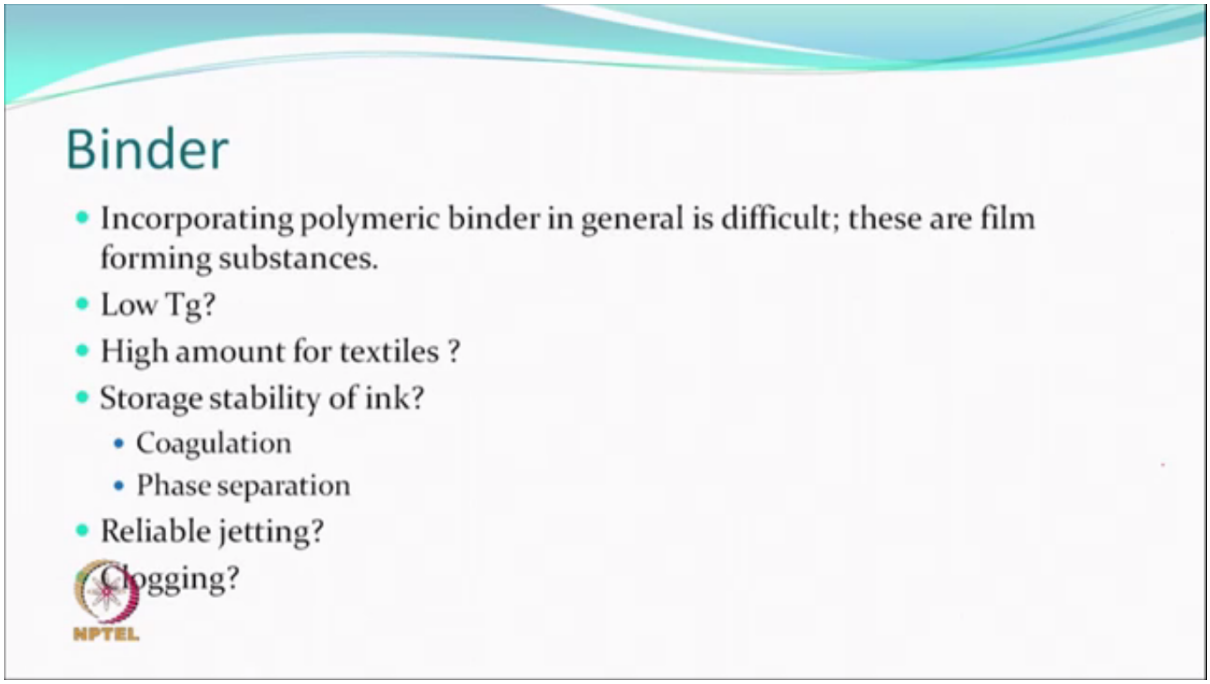

So clogging can take place.

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So we expect the binders to be generally soluble in the ink medium so that phase separation does not take place, but water insoluble, so that means you have other solvents, which will help the binder to remain in solution but -- and you have, but they will be generally in a way dispersed.

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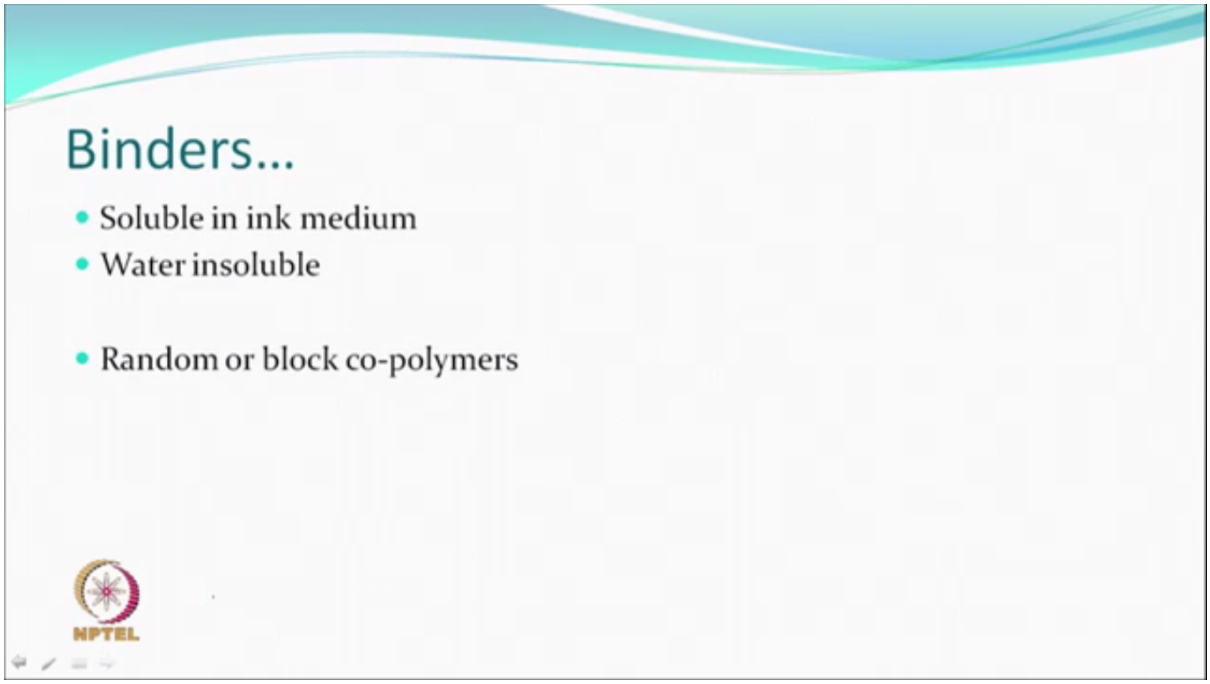

They are either random or block co-polymers of which have a soft segment so that you remember we require low glass transition temperature.

Cross-linkable or non-cross-linkable? In case they are the cross-link, they should be finally have the film, but whether the cross-linking should be done inside, it should be part of the ink or should be outside will have to be based on situations, but, normally, we would like the cross-linkable polymer, which can form a good film, which will adhere and have good wash fastness.

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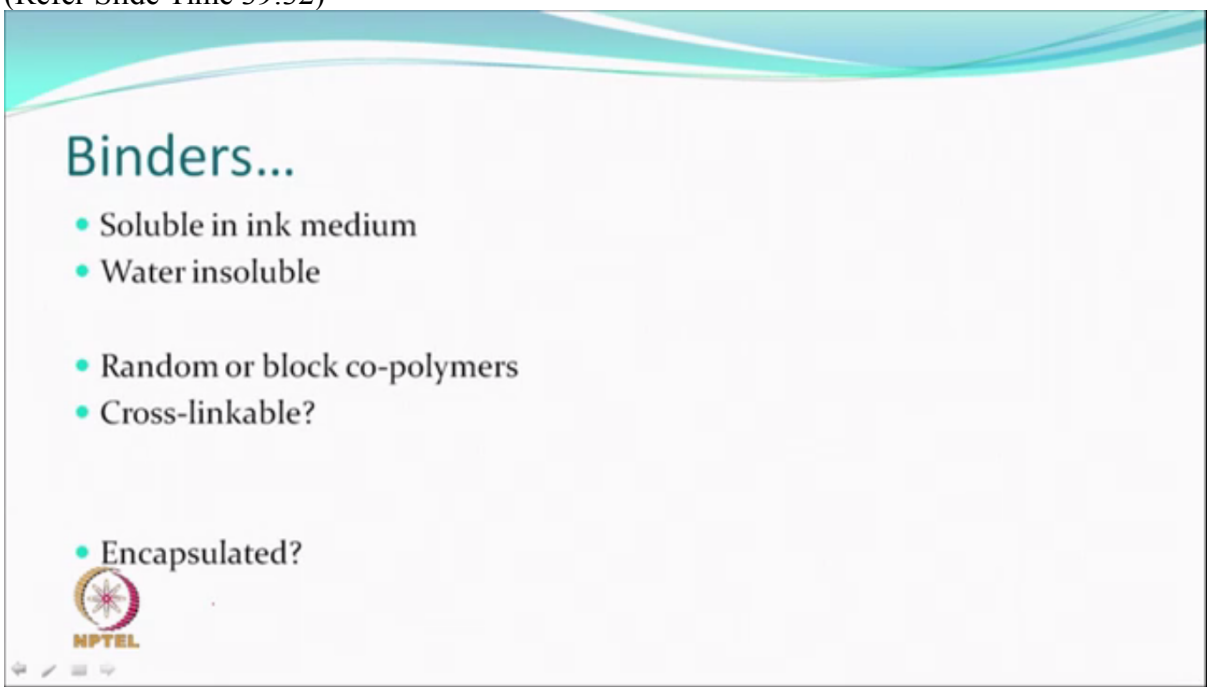

Sometimes to avoid these gelling issues because they are not water soluble or they're less water soluble, but they definitely are hydrophilic compounds to begin with, they may be

encapsulated and they get really exposed when they are outside. So they would not gel inside. They would not clog the material and once they are cross-linked, they will be, they'll become less water-soluble because if the cross-linking takes place before ejected, then it's a hopeless situation.

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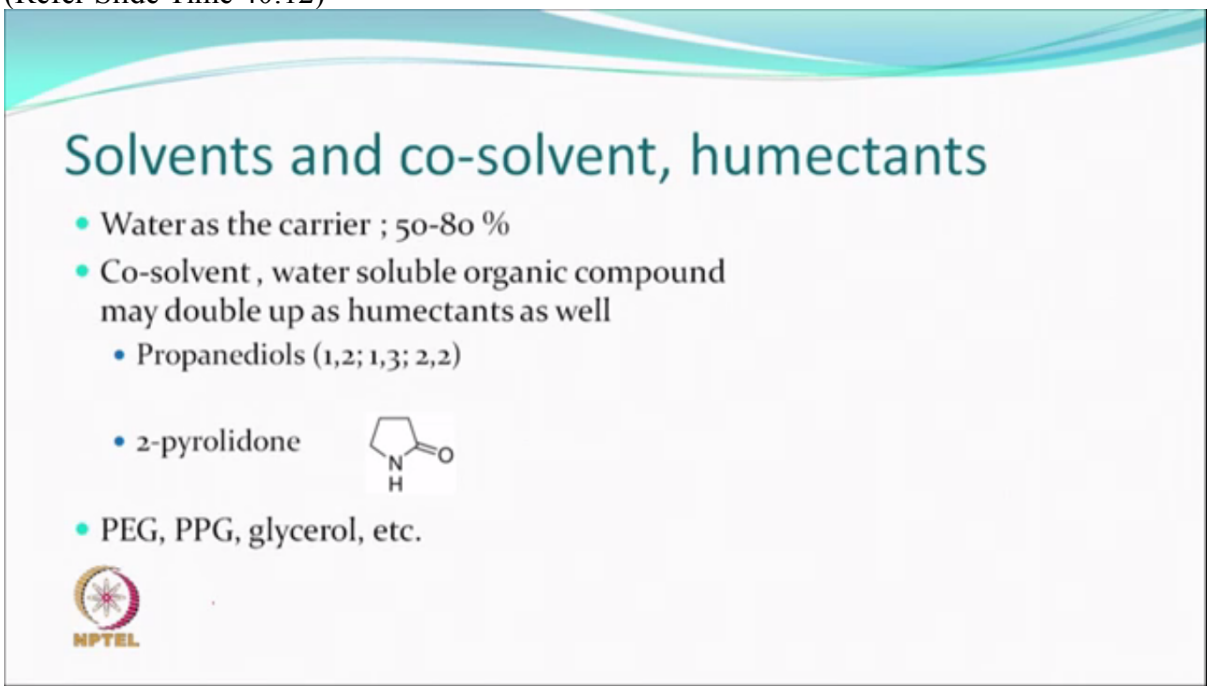

Some examples we can think of the solvents, co-solvent, humectants, water obviously is a carrier which may form about 80% of the volume. The co-solvent, water soluble organic compounds may also double up as humectants as well. That would means you will have to add less amount of material, for example, we just said propanediols or pyrolidones and polyethylene glycol, polypropylene glycol, glycerol etc., may form another group of chemicals to be added.

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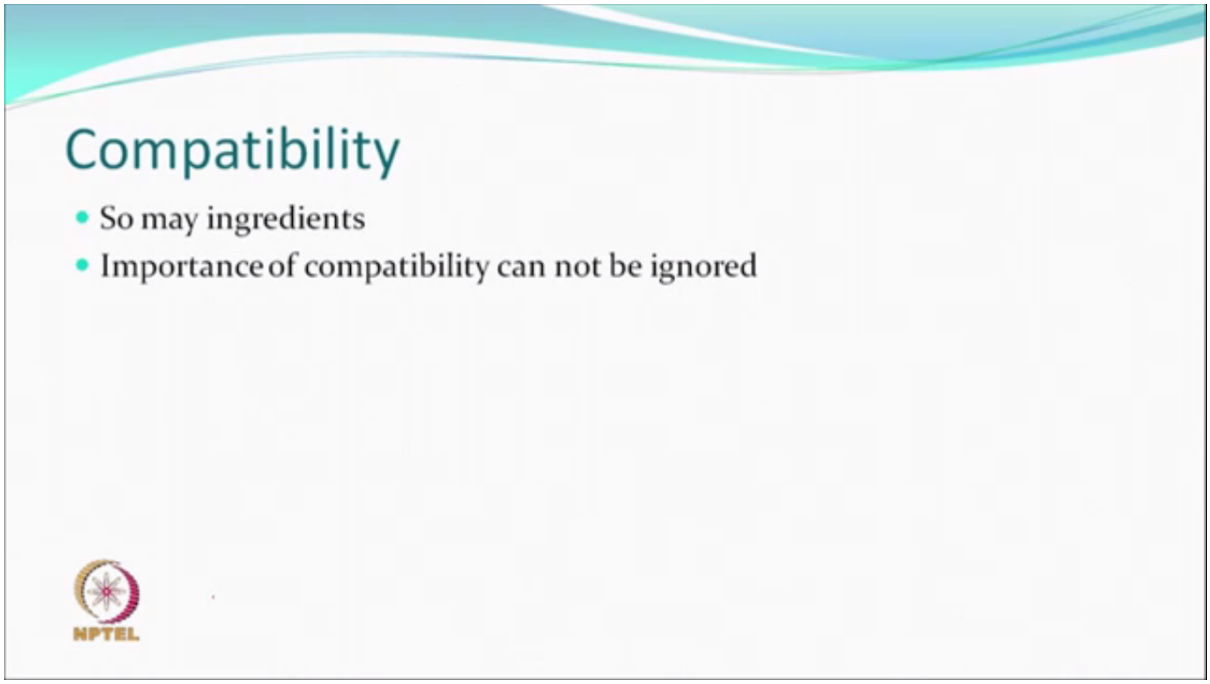

When we add so many chemicals, obviously, we will be looking at the compatibility. It should not happen that because of one or the other there is coagulation, settling and breakup of the dispersion.

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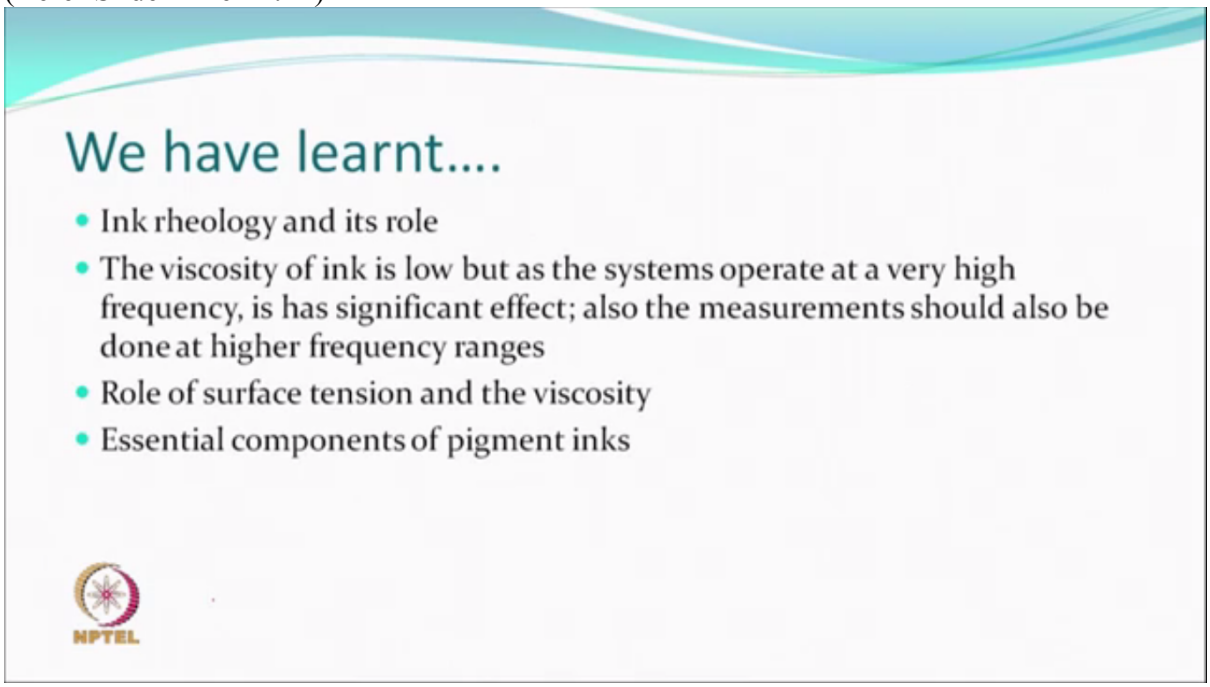

So, today, what have we learnt? We have learnt that ink rheology has a role to play. The viscosity of the ink is low but as the systems operate at a very high frequency, it has significant effects. The shear rates can be very high around the nozzle. The measurement, therefore, should also be done, measurement of this rheological measurement should also be done with instruments, which operate at a high frequency. Normal thing that we said we are operating at a very low frequency or which is not simulating the what is happening in the jet.

Role of surface tension and the viscosity is what we understood, and also we learnt as far as the pigment inks are concerned, what are the essential components.

So we stop here and next time we'll pick up other topic on this printing inks and maybe we will take up other types of inks used for inkjet printing.

Thank you.

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