Vibration Control

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Module - 7
Principles of Active Vibration Control
Lecture - 5
Electro-Rheological (ER) Fluids

Hi, this is Dr. S P Harsha, from Mechanical and Industrial Department, IIT, Roorkee, in the course Vibration Control, we are mainly discussing about the control techniques, and we broadly categorized those under passive vibration and active vibration control. In this lecture series we are mainly discussing about the principles of active vibration control, and in that we discussed that for controlling the vibration through these active vibration control features.

We need to know the sensing part we need to know the actuation corresponding, and then you see here how the control unit, which is being there to you know like amplify the things or you know like some kind of a external features are to be added to the actuation to balance that. And also you see here, then we found that there are various intelligent or the smart materials, which can be even acted as you see you know like the vibration control, means you know like the vibration control devices.

And they can you see induce, they can sense and they can induce the you know like the kind of forces, which in being required to suppress the vibration, in terms of you see you know like some repulsive part. So, the first material which was discussed was a piezoelectric materials, and we discuss that there are various forms right from you see the natural or the man made, these piezoelectric materials are being available.

There are certain limitations in the naturally available the piezoelectric crystals, so that is why you see the man made, piezoelectric you know like these features are being added to the materials. Even right from the ceramics to the polymers, and generally you see most common piezoelectric material, which is available and which is being used for the vibration control sensing is the p z t patches. Even, for actuations as well, in which you see here we have the lead, we have the zirconium and we have the titanium feature.

So, all three together you see here they have you know like sufficient strength and also, you see to sense and to actuate, when you see you know like some automatic control unit is being added in between that. And we discussed about you see that, these you know like the piezoelectric patches or the piezoelectric materials can be, you know like acted right from measuring the displacement to the acceleration. And piezoelectric the accelerometers they are excellent you see you know like we can say in measuring, the vibration right from you know like low frequency to high frequency vibration, and they are also you know like sensitive from the sensitivity is also very high.

So, in other means you see here when we are just talking about the measuring features the vibration, and then you means the sensing feature, rather I should say and then the actuations the piezoelectric material is the best one. But, sometimes you see here when you know like we need to just go, for you know like the different kind of applications there are various other materials, which are truly available and we can use those materials as well.

The first part in this is the electro rheological fluid, the ER fluids, and you see the next is the magneto-rheological fluid, then even we have you see you know like some kind of electro and magneto restrictive structures. Means, you see here like by applying the fields how we can you know like this, make a symmetric part in the particles when they are being subjected by these electrical or magnetic fields.

So, these are the specific materials under the electro or we can say the magnetic fields are there and then we are going to discuss about the shape memory alloys. So, in these category the first part is coming, as we already discussed the first part was there on the piezoelectric materials right from the characterization to the application part. And even you see here when we are trying to design, those things what are the key steps which we discussed already right from you see the principles to the application part.

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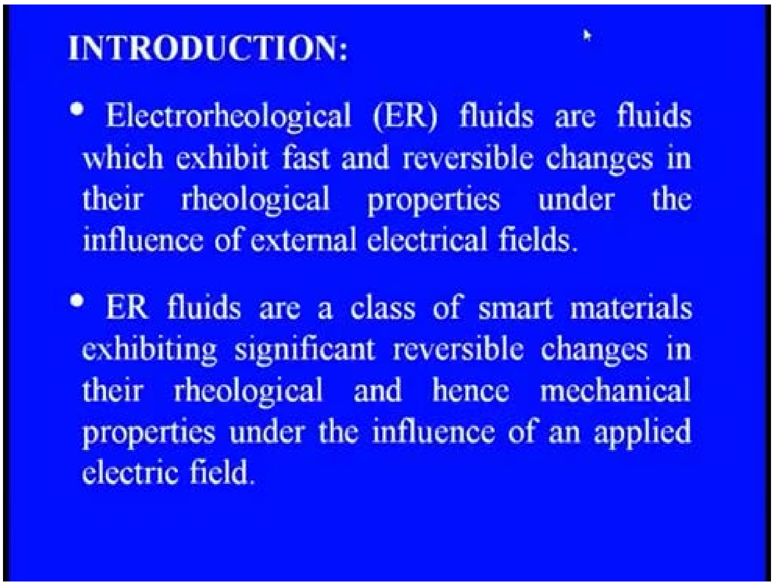

So, in this category now we are going to discuss about the electro-rheological fluids, and these are the fluids, which can exhibit fast and reversible change in their rheological properties under the influence of external electrical fields. So, that is why that is why you see here you know like the molecular properties the fluid properties, the you know like and this rheological part they have a straight influence.

You see here when there is a change in the electrical outside electrical field, and you know like ER fluids are a class of the smart material which can exhibit a significant reversible change, in their rheological. And hence, the mechanical property under the influence of this you know like applied electric field can be immediately change correspondingly, so we need to see that how these properties the rheological property of the fluid is really, so sensitive. Straightaway right from whenever the external, you know like these electrical fields are being applied, and when there is a change in their rheological properties, then how the mechanical properties are being changing under the influence of these applied electrical fields.

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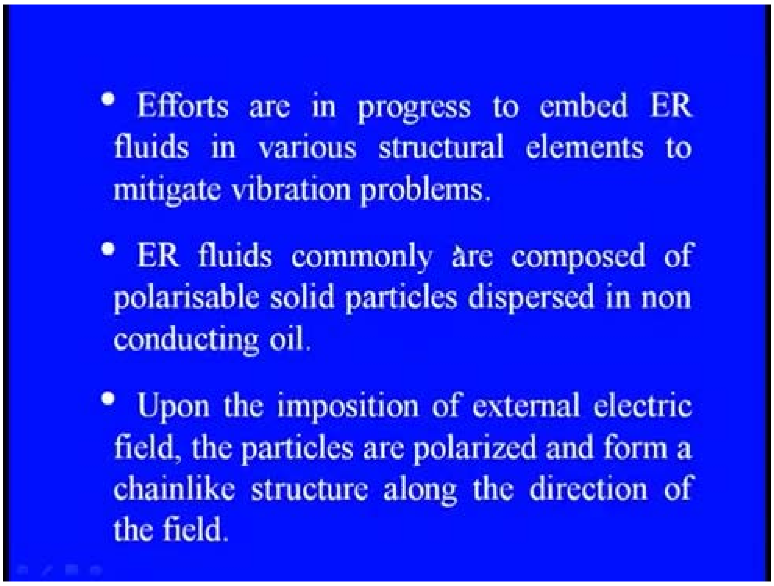

So, you see here, in these particular part the embedded ER fluids are always being there in the various structural elements, to mitigate the vibration problem, so once we know that you see they are you know like quite sensitive in that part. Then we can embed these things we can simply inject these ER fluids in the various structural element, just to mitigate this vibration problem.

And these ER fluids commonly composed of a polarized solid particles, which dispersed in a non conductive oil, because if it is a conductive oil then certainly you see there is a various other effects are there, which can even you know like imposed on these polarized solid particles. So, upon the imposition of this external electrical field, these polarized solid particles are simply, these particles are simply you know like being formed a polarized way, and then they are forming a chainlike structure along the direction of the applied field.

So, first part is coming when the electrical field are being applied to these solid particles along the layers, then they are simply first polarized, and the random orientation of these can be again make a chainlike structure, when the field is being applied, and this chainlike structure is just showing in one direction of the electrical field.

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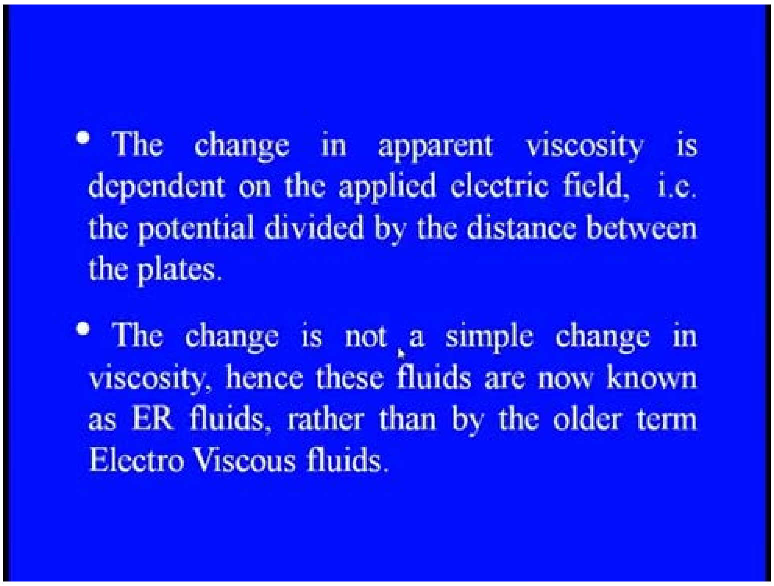

So, the change in apparent viscosity in this is absolutely depending on that what is the strength of the electric applied field; that means, the potential which is divided by the distance is you know like just existing between the plates. That to how much distance is there between the plate, according you see the potential features are being applied, to there. And then accordingly, there is a change in the viscosity of the fluid, and the change is not the simple change like you know like in the viscosity, these fluids are now known as the ER fluids, rather then we can say that it is a electro viscous fluid. It is not electro viscous fluids, because the change is not exactly just like the viscosity is changing, as we are just you know like putting some kind of external efforts, the changes are absolutely a chainlike structure all along the fibers.

So, the effect is better described as an a electric field dependent shear, so when there is an activation of an elasto, this electro-rheological fluid, then they are behaving not like the Newtonian part. If they are just behaving as the Bingham plastic in which there is a elastic feature, but again you see here there is some kind of the resistance or the viscous feature is there in that.

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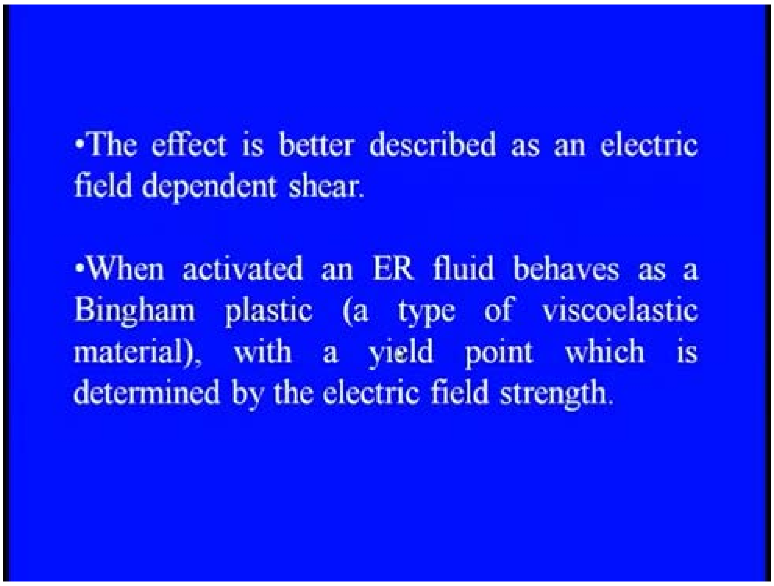

So, sometimes we can say that these ER when they are being activated, and when we are just trying to use that they are showing the stressed when relationship. You see whatever you know like this resistance or the deformation against the force relationship according to the Bingham plastic or we can say sometimes it is a viscoelastic material with a yield point, which is determined by the electric field strength.

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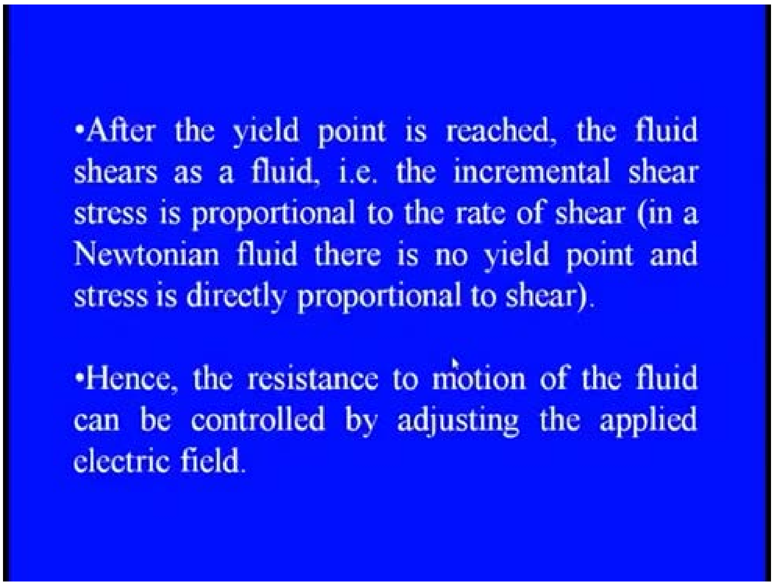

So, you see whatever the electric fields are there, accordingly you see here the proportionate elastic features are being coming, and there is a resistance which is being there due to the viscosity present in that. So, they are not a simple electro viscous fluid they are basically a Bingham plastic model based on that, so after getting the yield point the fluid shears as if the entire fluid which is just shears as a normal fluid.

So, this ER fluid upto you know like reaching up to the yield point the things are somewhat different, but once it is reaches there then it is a shearing part. And then you see they are simply showing the ER fluid just like a shearing part of the fluid; that means, you see here the incremental shear stress is absolutely proportional to the rate of shear. So, we know that, when we are talking about the Newtonian fluid as we know that it is a straight part, means the stress and stress, the stress and stream is directly proportional.

So, in this case you see here we have even not reaching up to the yield point the direct proportional features are there, but here we have first the there is no we can say the strain up to certain amount of force, because of the viscous part. They are absorbing and then they are showing a linear feature between the stress and the rate of strain, hence the resistance to motion of the fluid can be controlled by adjusting the applied electric field.

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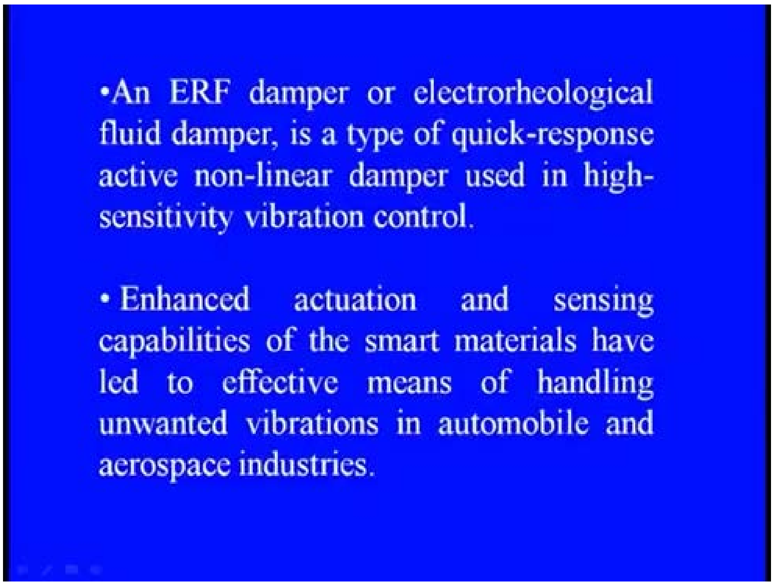

So, we can say that the ERF dampers, which is simply based on you know like the electro-rheological fluid ERF, the ERF damper or electro-rheological part the concept you see here is a type of quick response. Active non-linear dampers, because certainly you see here they are not showing any this Newtonian part, so non-linear damper used in high sensitivity vibration control, because we know that first of all as we just want to increase the resistance.

Just we can only you know like increase the this electric field outside, and they are clearly exhibiting the yield point and beyond yield point. Whatever, the shearing features are there with the molecules under these polarized feature, they are simply proportional to the rate of shear strain. So, if we want to enhance the actuations and sensing capabilities of the smart material, then they have to lead, to the effective means of handling unwanted vibration in automobile and aerospace industries.

So, certainly you see here these materials in which there is a clear relations between the molecular orientation, and the electric field can be acted under the high sensitive vibration measurement. And then they can be act as the sensing, and the corresponding actuation part in that can you straightaway used, as you see in automobile or aerospace industry, but again you see here one of the key feature is the strength of the applied electric field.

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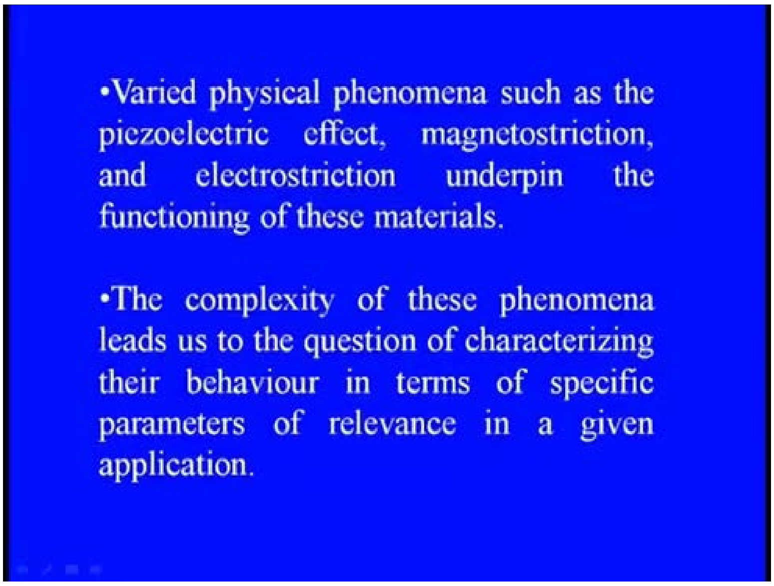

So, when we are varied the physical phenomena such as the piezoelectric effect, or we can say the magnetostrictions, or we can say even the electrostrictions, underpin the material or the functioning of these materials are absolutely. You know like we can say changing with that, the complexity of these phenomena leads, that you see we need to characterize their behavior in terms of the specific parameter of the relevance.

According, to the application where it is to be required just for vibration control, or sensing feature or you see here what exactly, you know like the kind of a damping part which is to be required there itself or how much resistance is to be applied there.

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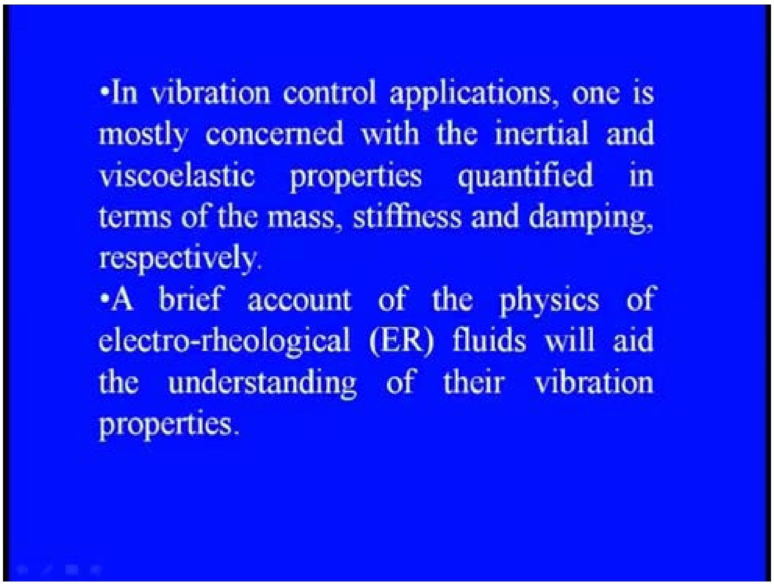

So, when we are talking about the vibration control application, one of the most we can say one is the mostly concerned with the inertial, and viscoelastic properties can be quantified, in terms of the mass stiffness damping as we have already checked. And if we are just talking about the physics of this electro-rheological fluid, then we can see that they have the corresponding features through, which we can control the vibration. Through, these you know like the strength of the electric field and the polarization effect for absorbing, and for it giving the resistance towards that.

So, we can say an electro active material is nothing but is a suspension where a semi conductive material, like we can say either the semi conductive is in a particulate or we can say the liquid form is dispersed in a dielectric liquid medium. And the rheological property change in the reversible form by several orders of the magnitude, under these external electric fields. Like you see the rheological property can easily be controlled within the wide range, and then you see we can straightaway develop for various applications.

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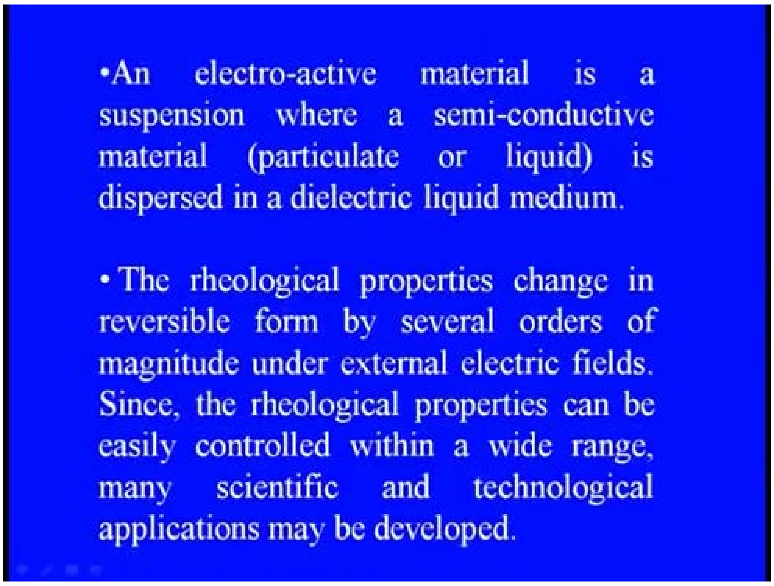

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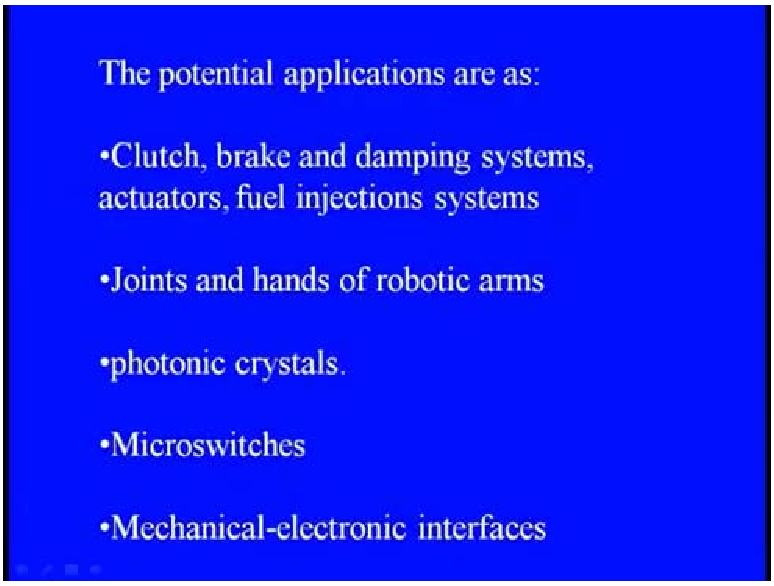

And the potential application, when we are talking about is the clutch, the brake damping system actuators fuel injections system, so these are you see here, the one part which is coming under the IC engine category. Even, they can be you know like the straightaway put, in the joints and hands of robotic arm, for smother control at the high sensitivity level.

The photonic crystals the micro switches, even for mechanical and electronic interfaces parts, where you see both the things are being you know like interfacing together. There we can use these ER fluids, and they have they are showing a good exhibition even in the recent time they can also be used when you see the train is just moving. And if there is a chance of the crushing, when there is an impact there if you want to reduce the damage, to the subsequent coaches, then you see these ER fluid dampers can absorb the huge amount of energy. And they can restrict whatever you see the impact energy which is being transmitted to the other coaches, so still the research is going on on that, but there is a great application of these, and we can straightaway put for you know like, just to safeguard for other coaches in that.

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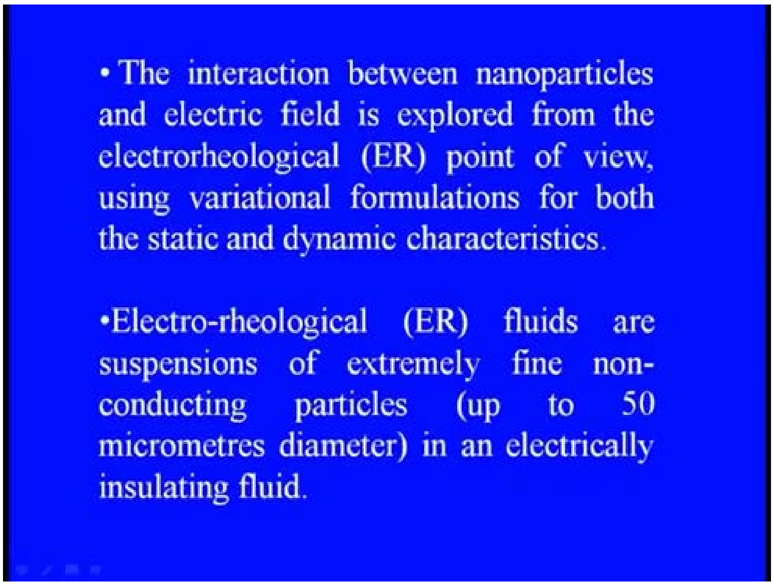

So, the interaction between the nanoparticles and the electric field, which is being mainly explode in that, and we can also use the variational formulation for both the kind of characteristics under the ER fluid part, like the static and the dynamic characteristics. So, ER fluids are nothing but the suspension of the extremely fine, non conductive particles, so if we are talking about the particle size.

Then they are only up to the 50 microns diameter, and when we are saying that, when these particles are suspended, if these you know like means these fine particles, basically the non conductive particles we can say rather in an electrically insulated field, we can get a well streamlined ER fluid properties.

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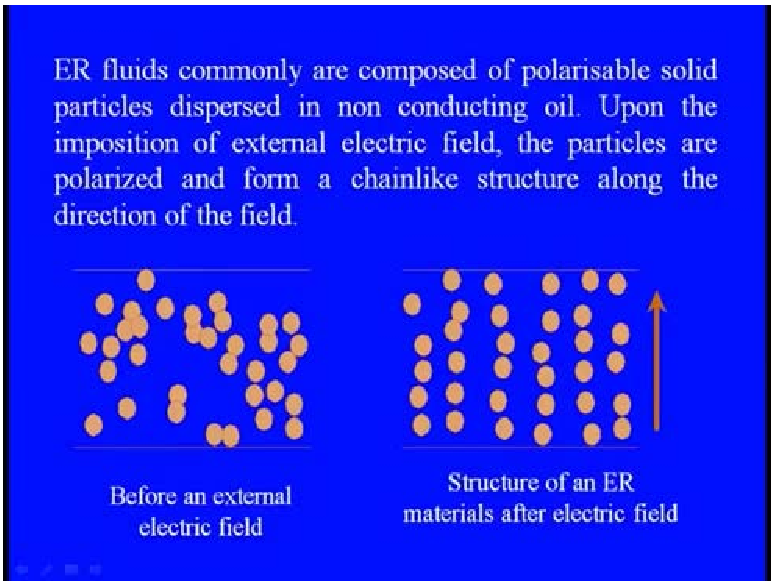

So, ER fluids commonly we can say the composed of the polarized solid particles as we discussed, and they are being dispersed into a non conductive oil for a domain part. And upon the imposition of this you can see that, we have these particles which are being a randomly orientated there. And they have you see since they these are the non conductive particles, and since you see here, they are being now polarized by applying these things by applying the electric field.

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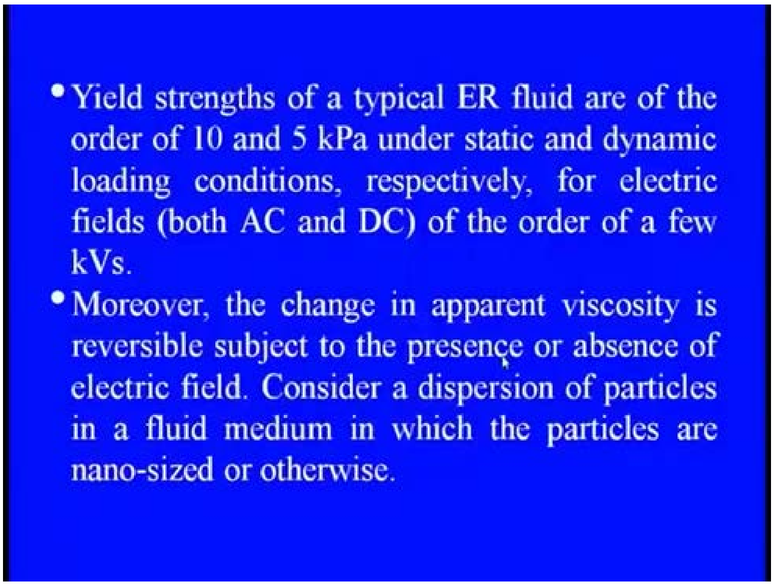

Now, when the ER field is being active means, when the electric field is being acted then all the rheological feature of these material, means that fluid part they can be well streamlined and they can exhibit. You see a clear properties, which we require, because now they are aligned, in that same direction, where the electric field is being applied there.

So, when we are talking about the mechanical feature, then the yield strength of this typically ER fluid, which are in the order of 10 to 5 kilopascal under static, and dynamic loading condition. And even, for both AC and DC electric fields of the order of few kilovolts kv's, so when we are just applying, these you see you know like the electric field in k v's, we can at least get the yield strength in this part.

And moreover the change in apparent viscosity, as we discussed it is having a reversible effect in the presence or absence of this electric field. So, when we are considering a dispersion of the particle in fluid medium, in which the particles are nano sized or otherwise, we can be straightaway formulize those particles under the effect of this electric field. So, when we are talking about the classification of this electro-rheological fluid, then we have the two broad categories in this, one the liquid phase and one is the dispersed phase..

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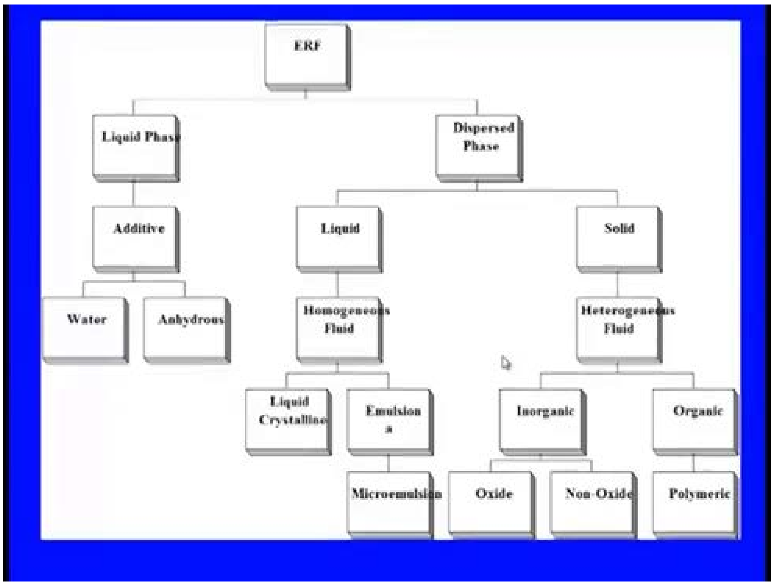

So, when we are talking, when you know like we are categorizing this electro-rheological fluid in the liquid phase first, then the first thing is coming what is the additive part in this, whether we are talking about the water or rather we are talking about the anhydrous. So, accordingly you see the liquid phase is to be, you know like implemented and then we can get those rheological properties in that, but when we are talking about mainly, the dispersed phase.

There the two parts is coming, one is the liquid in which the homogenous fluids are there, which we are always putting together in the homogeneous features in that. And when we are talking about solid then also we are we are trying to keep the homogeneous fluid within that, and under the liquid homogeneous fluid, we can say the two main parts are there.

One is the liquid crystallization that what is the liquid crystallined features are there, in the electro-rheological fluid a second is there what is the emulation, because this is also you know like some kind of you see the liquid part, which is to be provided under the dispersed phase. And then you see when we are talking about the emulation; that means, you see what is the micro emulations are there, means you see how these micron size of means that is only up to 50 micron size.

You see these immolation features are there, but when we are talking about the disperse phase in the solid part, even in the under the homogeneous fluid then we can say there are two main categories, the inorganic and organic. When we are talking about the organic, then we have a clear cut the polymer feature, and when we are talking about the inorganic, then we have the oxide and non oxide part. So, this is you see you know like the broader, we can say classification of the ER fluids, when we are starting from the dispersed, and the liquid phase.

And when we are ending up to whether the water or we can say the microemulsion or oxide non oxide or the polymeric features of the organic dispersed solid homogeneous fluid. So, when an electric field now, because we know that this is the two broader feature are there, one what exactly, these solid particle which are being polarized and what is the strength of the electric field through, which we can define the resistance provided by this.

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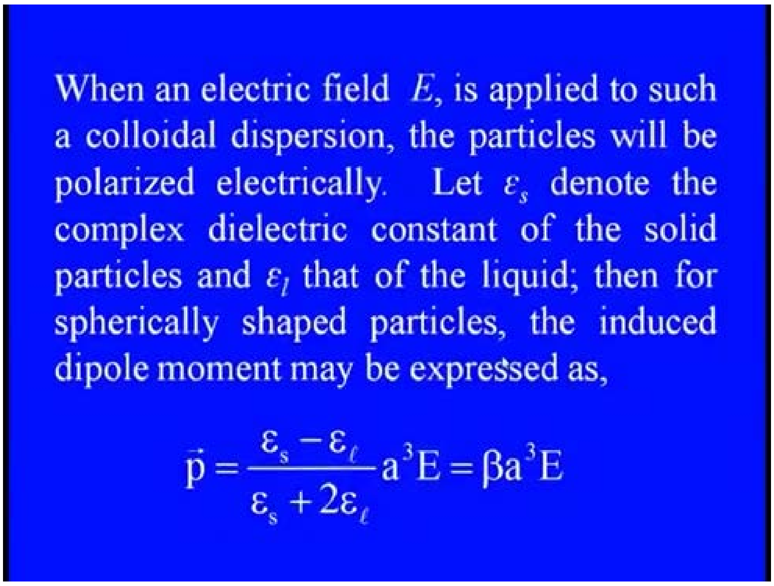

So, an electric field E say you know like, the E generally we are using is applied to such colloidal dispersion of the materials or the particles, the particles will be polarized electrically straightaway. And we can say that the epsilon s, which we are always using the complex dielectric constants for this because right now, now we have the polarized particles, electrically polarized particle. So, these solid particles they have the complex dielectric constant that is the epsilon s, and also we can say that we have the spherically saved particles in which we can say whatever the liquid part is there, for this the complex dielectric constant is epsilon l.

So, now you see we are categorizing two parts, epsilon s for solid particles, epsilon l for liquid particles, and you see here we can simply characterize their dielectric constants under this. So, when we have you see you know like the spherical solid shaped particles, we can say that the dipole moment, which is to be induced under the action of these electrical field, which is applied there. We have the dipole moment p is equals to epsilon s minus epsilon l, means the difference of the dielectric constants, under the influence of this electrical field in we can say you know like the solid to liquid.

Divided by epsilon s plus 2 times of epsilon e into a cube E or else even, we can simply put the constant epsilon s minus epsilon l divided by epsilon s plus 2 epsilon l. That is absolutely a constant term, because it is a specific property or inherent property of the fluid part, which is to be there inside the entire system. And where you see now, when we are just keeping the beta, which is the constant one you see such showing that into a cube E, where e is the applied electrical field, and a is the radius of particle.

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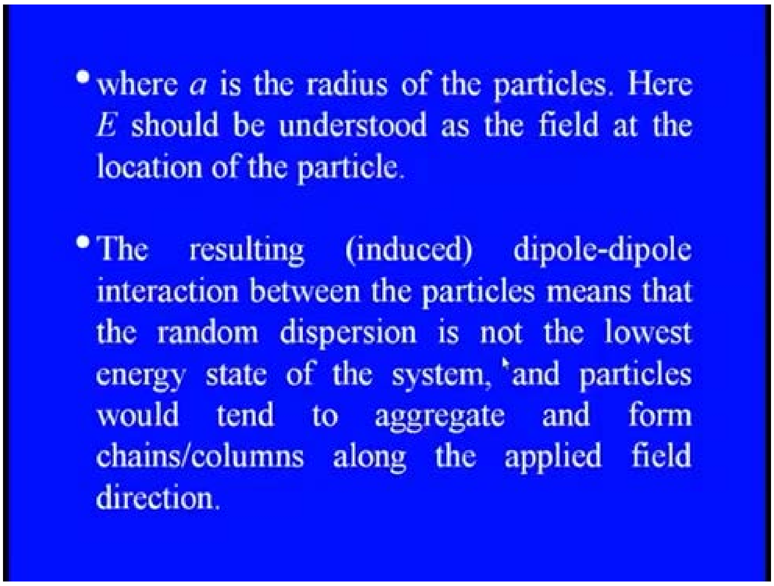

And one of the important part here, the electric field is the only specific field which is being applied at the location of the particle, means it is a very specific region there itself. So, whatever the induced dipole interaction means dipole, dipole interactions are there between the particle means, then the random dispersion is not the lowest energy state of the system. The particles would tend to aggregate, and form the chains or the columns according to the applied field directions. So, these random dispersion now, is being really characterized according to the dipole dipole interactions, and then you see here these whatever the stream line features are there, in the you know like these particle is being decided by this applied field directions.

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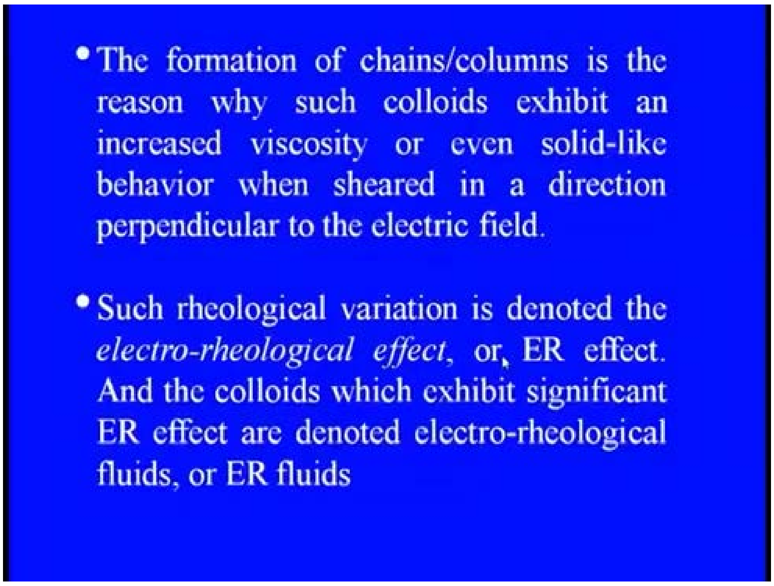

And the formation of chains or these columns whether it is in the chains or the columns is the region, why such you know like the collide exhibit an increased viscosity .That means, you see whatever the formation of these chains or the columns are there, they are mainly due to the viscosity is increased, or even we can say this is something the solid like behavior, when sheared in the direction perpendicular to the electric field.

So, you see here when an a electric field is applied, the two things have being happening, when these the collide features are there, the viscosity is being emerged out. And accordingly, you see here they are simply showing a streamline character or one we can say the line character or in other way also. That can be you will stand by that they are simply showing a solid kind you know like these fluid particle the solid kind behavior, when the shearing action is being happen, because the normal direction is perpendicular in the under the action of the electric field.

So, they are absolutely you know like shearing action with these two part, and such rheological variation which we are saying electro-rheological effect, can be straightaway featured out under the action of these electric field and the polarized particles. And the colloids, which is one of the important part here, which exhibit the significant ER effect, can be we can say that you know like just considered under the electro-rheological fluidic features. That how much you see this colliding features are there, and after that you see how they are just streamlined in the, you know like the column or the chains part.

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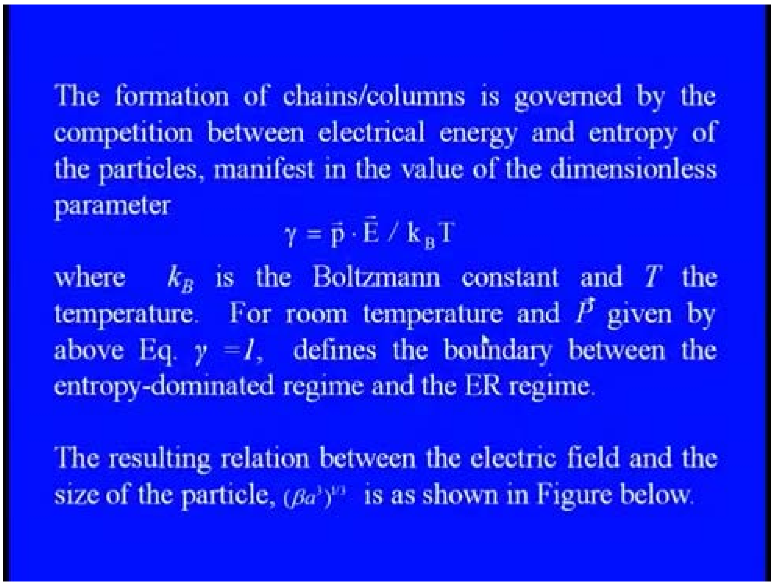

So, when we are saying that there is a formation of the chains or the columns, which is being governed by the competition between the electric energy and the entropy of the particle. This is one of the important feature here, that the electric energy is being there because of you see we are polarizing and applying the electric field, and what the entropy the disorderness is there the randomness is there in that.

We can simply manifest in the dimensional less parameter gamma, in such a way that the p into e, where we have already discussed about the, you know like this dipole moment into the applied electric field divided by k b into t. Where, k b is the Boltzmann constant and t is the applied, whatever the room temperatures are there, so we can say that when we are just discussing all that part that you see what exactly.

The collation under the collation what exactly the relations are there between or what the you know like the exchanging features are there between the electric energy. And the entropy of these particles, because ultimately, when we you know like putting the electric field we know that after certain time, they are always being along the chain or the columns.

So, whatever the entropy or the disorderness is there in the system is being reducing, so we can simply get this you know like with this the non dimensional parameter, gamma which is nothing but equals to p into e divided by k b into t, as we discussed. And for the room temperature and for any given p, we can say that it can be straightaway find out that what the Boltzmann constant are in are there in between that. And even when we are saying that the gamma equals to one; that means, it just says that what exactly the boundaries are there between the entropy, and the dominated region.

And then how the ER region can be formulated in that manner, which can show the linearity means the minimum, we can say you know like the disorderness or the laminar feature. And the resulting relation between the electric field, and the size of particles which is you see you know like the beta into a cube as we discussed, in that beta into a cube to the power 1 by cube which clearly shows that, we have a clear you know like the variation as you can see here.

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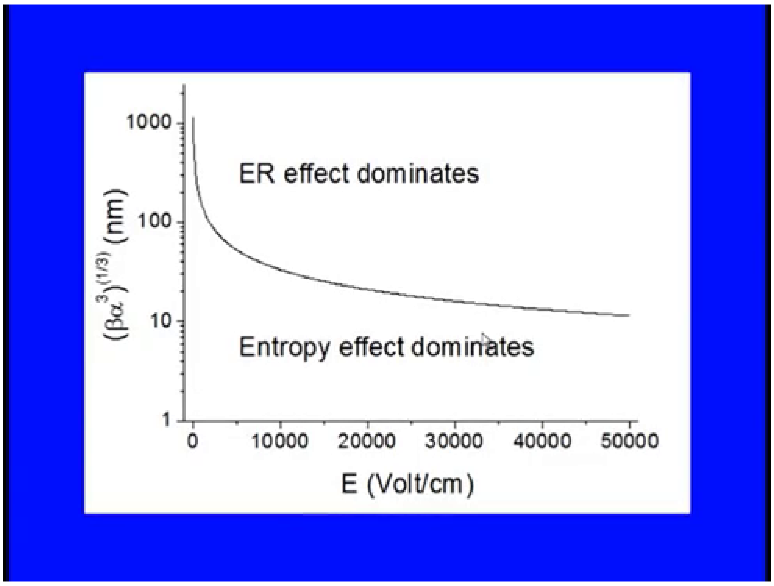

As, this particle size which is being you know like increased the right from 1 to 1000 part, then we can see that, when we have the particle size very high, certainly the disorderness will be more and at that time, the entropy effect is dominating. And when even you see here, when we are trying to you know like increase the electric field, and if we have you see here you know like the more means I mean to say actually the particle size is quite significant even more.

Then also you see here the electro the electro-rheological region is dominating, so this is a very clear relation between the particle size applied voltage, and then you see here which region is being dominated. Again, when you have E 1 the higher electric voltage, which is being applied there, and the particle size is even low in that case also the entropy effect will be dominated, you can see that this. At this region even we have a very small particle size, and we are just increasing this electric voltage, in this entire region the entropy effect is dominating. While, even if you are just increasing that part and if we are add the certainly at the lower voltage, the most of the significant feature is the ER part, and as it is just increasing is as we are increasing the voltage the ER effect is dominating with E 1 the 100 particle size.

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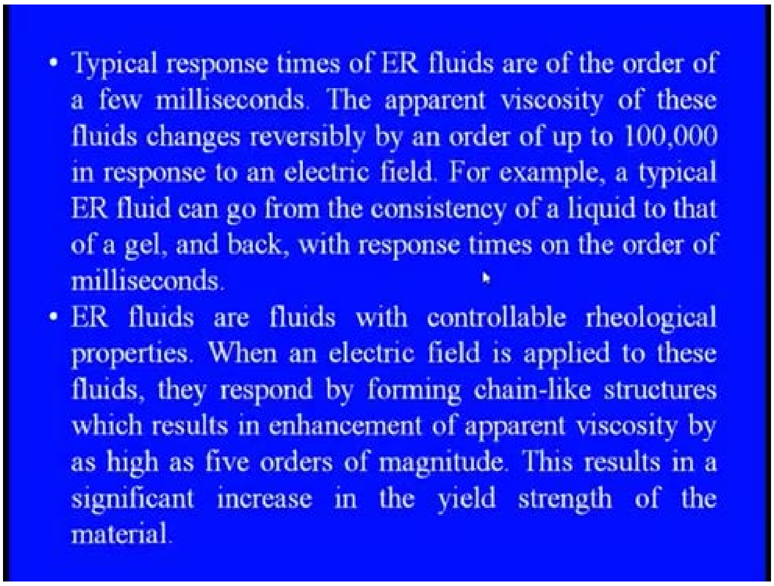

So, this typical response times of ER fluid are in the order of few milliseconds, the simply you know like just showing is this d k part, the apparent viscosity of these fluids changes reversibly by an order of you see the 1 lakh in response to the electric field. So, if you have just taking one example say, a typical ER fluid can go upto the consistency of liquid to that of the gel, and back you see in the same manner with the response times of on the order of the millisecond.

So, this is the clear feature that is why you see we are saying that this ER fluid dampers, or the sensors they are very sensitive. So, ER fluids are the fluids with controllable rheological properties, they can exhibit and excellent features, and when an electric field is applied to these fluids, the respond by forming a chainlike structure, with resulting enhancement of the apparent viscosity by as high as five orders of the magnitude, and these results in the significant increase in the yield strength of the material.

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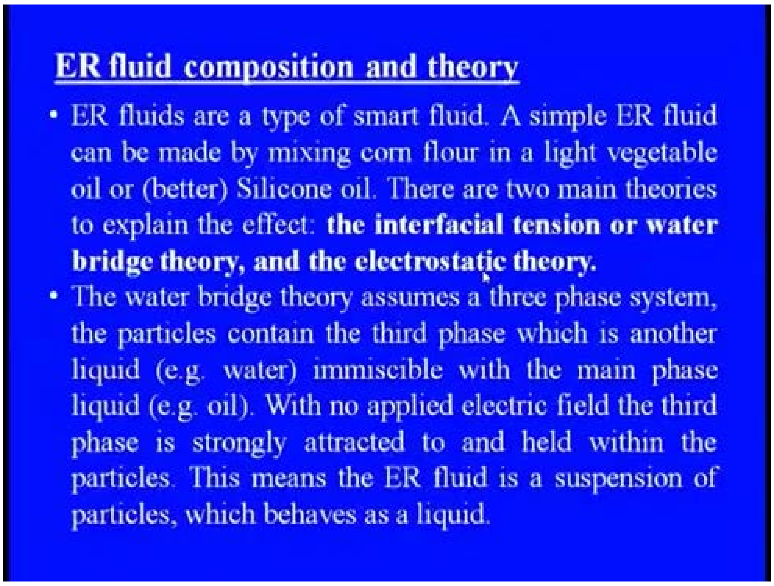

So, now if you are talking about the composition ER fluid, then we know that these are the type of smart fluid, and they can be made by mixing a corn flour into a light vegetable oil or we can say a silicon oil, rather which is more convenient. And there are two main theories, through which we can explain the effect, one the interfacial tension in between you see say the corn flour part, and you see the silicon oil or we can say means in the interfacial tension or the water bridge theory.

And second is the electrostatic theory, so these two theories you know like, we can say that how the particles are being formed with the you know like the mixing of the non conducting oil. Like we can say like vegetable oil or the silicon oil, and then the other part is like the corn flour or any kind of this feature. So, in the water base theory is being considered, then it assume that a three phase system, in which the particle contain the third phase, which is another liquid say you see the water immiscible.

Just you know like this immiscible with the main phase of liquid is oil, and with no applied electric field the third phase is strongly attracted to and held within the particles. This means that the ER fluid is a suspension of the particle, which behaves as the liquid part, so this is you see the water base theory which can be straightway acted, between you see here. Whatever, the particle flow the means you know like what are the subject particles and the liquid phase is there, so the subject phase is we can say you know like just like the water in something and the main phase is known as the liquid part. It means we can say that the oil part or any kind of you see the main domain, in which the things are being merged. So, you see here you know like, we can say the whenever you see the ER fluid parts are there, this is nothing but the suspension of the particles, in which they can behave as the liquid.

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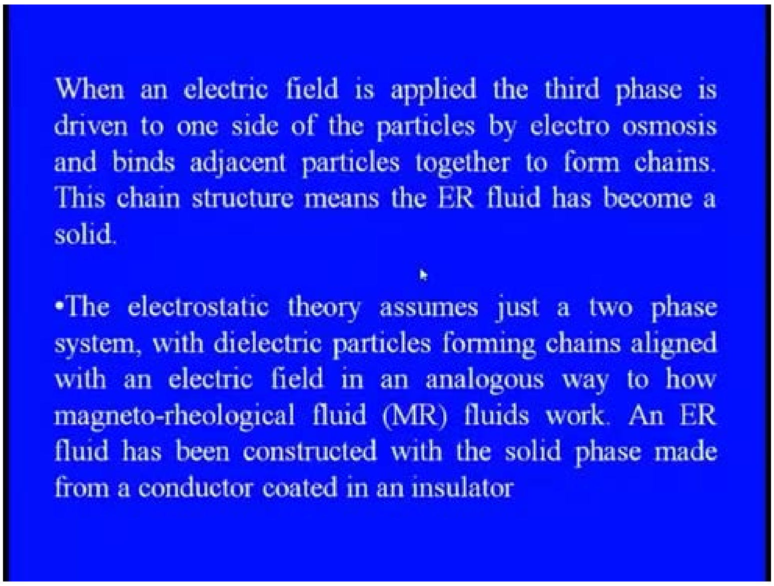

And when the electric field is applied on this third phase, which is driven to one side of the particle, by the electro osmosis feature, and then they bind in the adjacent particle together to form a chain, and this chain structure is simply showing that the ER fluid is exhibiting a solid nature. So, this is a clear feature before applying the electric field, we have a liquid phase is the liquid structure behavior, and after applying the electric field, we have a solid kind of behavior from the same ER fluid.

And the second theory the electrostatic theory is simply assumes just a two phase system with the dielectric particles forming a chain, which is aligned with the applied electric field in an analogous way. To how the magneto this MR fluid is working, see we are also going to you know like discuss about that, so we can say that the ER fluid has been constructed with the solid phase, made from the conductor coated in an insulator part.

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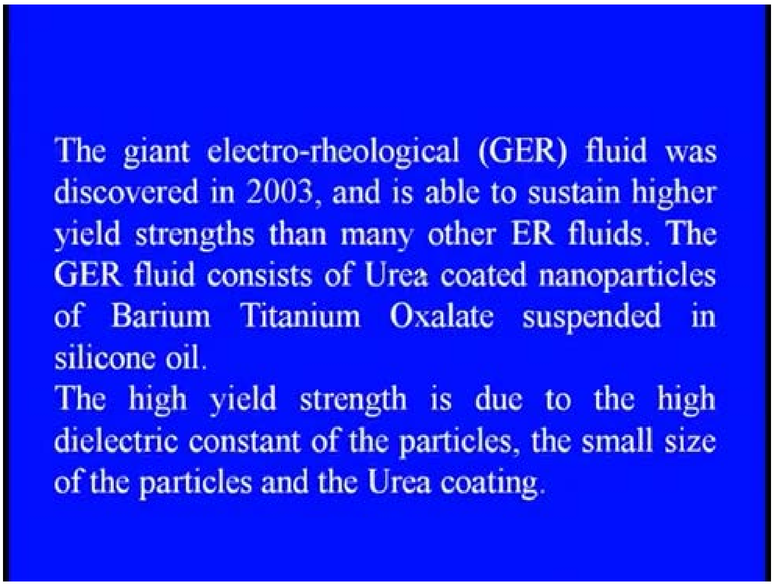

And you see the giant electro-rheological fluid, the GER it was been discovered in 2003, we can say in somewhere you know like in which in you know like we can say the u k part. And they are simply showing, that they are able to sustain the high yield strength, then the normal ER fluid, because they are consisting a urea coated nanoparticles of the barium titanium oxide, which is suspended in the silicon oil the non conductive oil.

So, now the things are somewhat change, they are simply used a specific featured the nanoparticle, in which you see here, they act simply you know like put in the barium this we can say titanium oxide, and then they can be suspended in the silicon oil. And by adopting this when the yield strength is increasing, the high yield strength is mainly due to the high dielectric constant of the particle.

And the small size of particles and whatever the urea coating is there, so these are the 3 main featured, in which we are just saying that when this nanoparticle, which is being coated by the urea. And you know like of this we can say a barium titanium oxalate, they can simply exhibit, the high dielectric constants. And since, because of this small size they can show a great yield strength, which can be we can say a form for various applications, and one of the another advantage of this GER. The GER as the you know that gained electro rheological part is that the relationship between, the electric field strength and the yield strength is linear after the electric field is reaches up to 1 kilowatt per millimeter.

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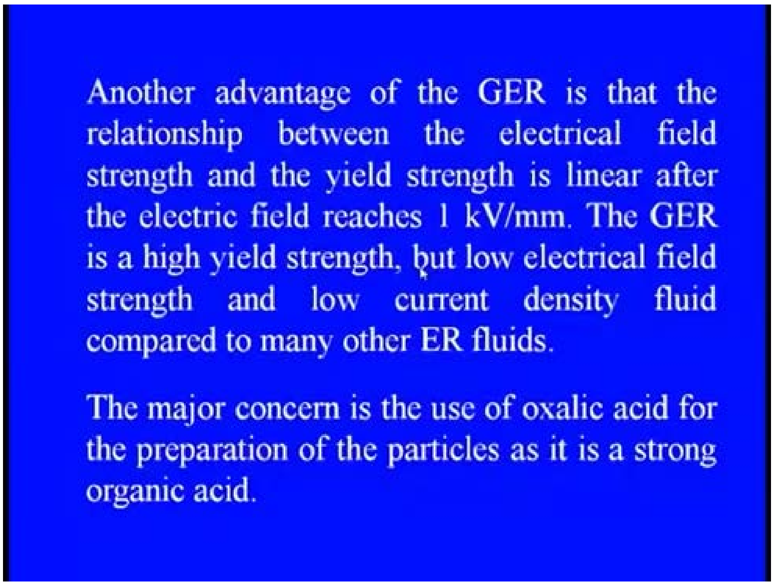

So, you see here, we can clearly exhibit the linearity feature between these electric field and the yield strength up to a certain limit, beyond that part. And the GER is a high yield strength, but low electric field strength, and low current density fluid compared to the common ER fluids. So, the major concern is the use of this oxalic acid, for preparation of the particle as we know that they are the strong organic acids.

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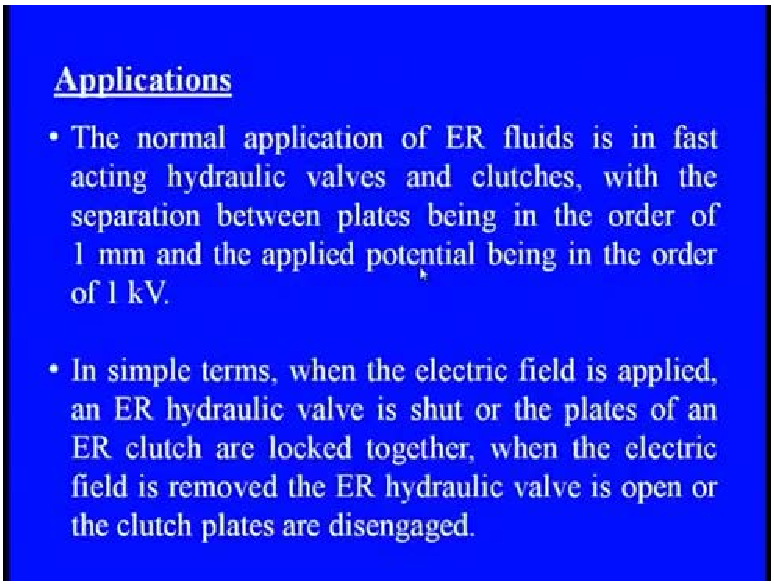

The normal application if this ER fluid is in the fast acting hydraulic valves and the clutches, with the separation between the plates in order to you know like, we can say 1 millimeter. We can applied the electric field almost up to one kilowatt, and we can straightaway apply in these kind of you know like the actuation, or the sensing part under the hydraulic valves or clutches.

So, in simple terms we can say that when the electric field is being applied, this ER hydraulic valve is set or we can say the plates of the ER clutches are being locked together. And when, the electric field is removed this ER means electro-rheological hydraulic valve is open, or we can say the clutch plate which is being made by this ER fluid is disengaged. So, this is you see the simple, you know like we can say the relation when the this electric field is being applied or the absence of this.

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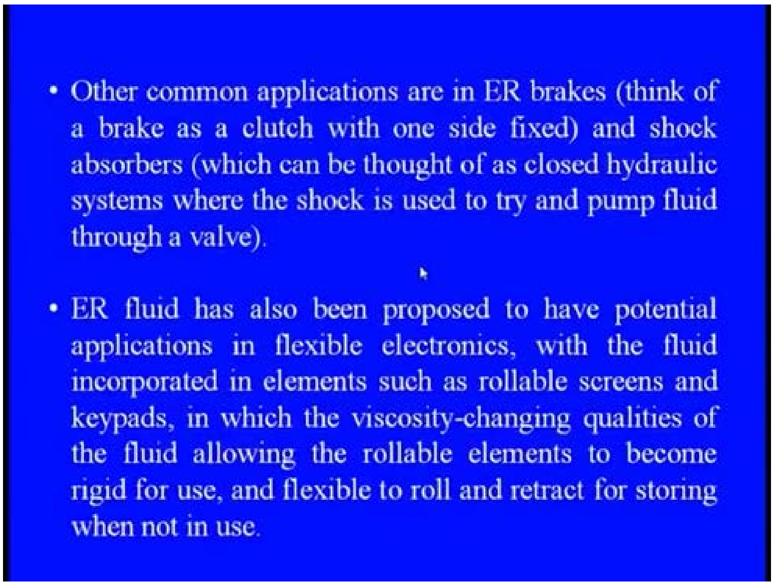

The other common application are ER brakes, we can think that you see that the brake or a clutch even you know like an fixed on one side. And the shock absorber also, which can be even thought of the closed hydraulic system, where the shock is used to try and we can say the pump fluid through the valve. So, you see here that the shocking features can be straightaway absorbed, and even you know like dissipate the features, so ER fluid can be not only acted as the straightaway controlling the motion through valves or brakes or something, but also you see here.

They can be acted as the damper part, in which you see the absorption the shock absorption can be happened, and they also you know like being proposed to have the potential applications in the flexible electronics. In which the fluid is incorporated in the element such as we can say the rollable screen, or the keypads at where the viscosity changing the quantities of the fluid. And which you see allowing the rollable element to become rigid, for use and also flexible to roll through which the you know like, the retract for restoring when it is not being used.

So, it is just you see a kind of when it is being used, it can be simply you know like allowing the viscosity changing properties for such kind of you know like the action. And when the things are being not you know like there, then it can be you know like retract for storing when they are just free not in use.

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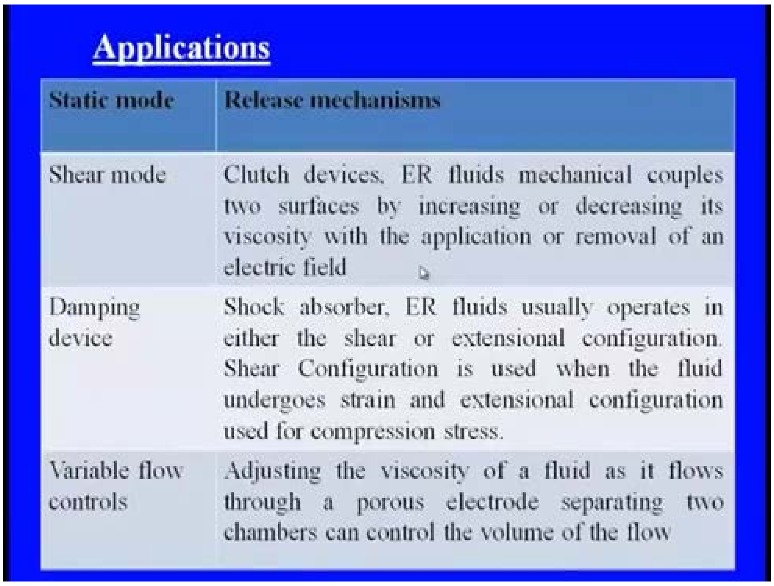

So, now we can see that there are 3 modes accordingly you see, the mechanisms are there under this, when we are talking about the shear mode, which we are all talking about. We know that the various release mechanism is there under that, one is the clutch device in which the ER fluid mechanical, couples two surface by increasing or decreasing its viscosity with the application or the removal of electric field.

As, we discussed when we apply the electric field these ER fluid clutches are being engaged, but this is the absolute shearing mode in you know like in the particle, when the electric field is being applied. And when, we you know like just remove the electric field, this shearing effect is just released, and there is a disengagement between these clutch plates. Even, the damping device which you discussed, the shock absorber the ER fluid usually operates in either the shear, or we can say the extensional configurations.

And this shear configuration is used when the fluid undergoes the stain, and extensional configuration used when the compressive stresses are there. And they can immediate you see dissipate the energy and the same time they can absorb the energy, because they have you see the potential in between the this ionized particles. The variable flow controls in this adjusting the viscosity of a fluid according to the applied we can say electric field, as it flows through the porous electrode.

As it just flows through the porous electrode separating two chambers, can effectively control the volume of flow, and by this we can rather use that. This is some of the controlling feature or the devices, where we just need an accurate flow the discharge part from these channels. So, this is you see something you see whether we are talking about any kind of flow, they can be act as the clutches or we can say that, they can be act as the storing device. They can be also act you see here as you know like the controlling feature, when the flow a part is being controlled or even you see we can see that, when we are just talking about this the braking system, the ER brakes are also one of the effective feature through that.

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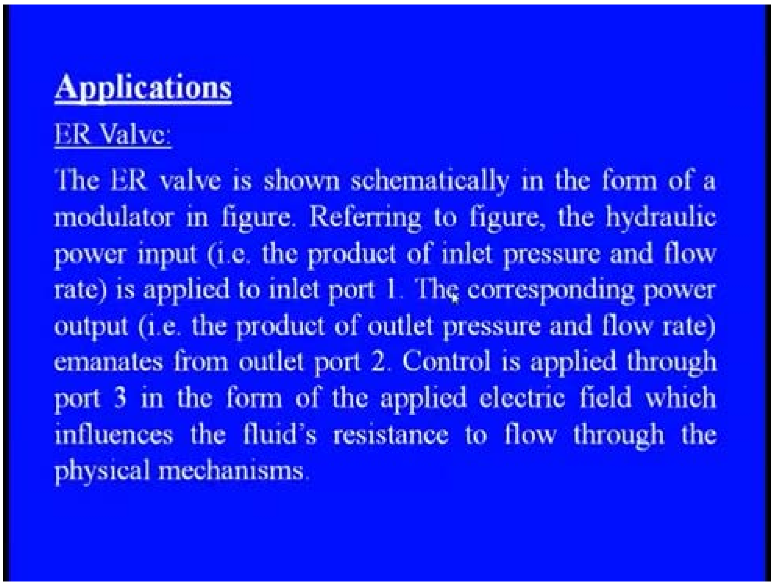

So, as we discussed you see you know like the ER valves, which can be we can say that you know like it is a kind of the modular form, in which the hydraulic power inputs are there. That means, you see you know like we have the inlet pressure, and the flow rate which is to be applied there, and then we can get the correspondingly control, which is simply we can say according to what the fluid resistances are there to flow through the these mechanism.

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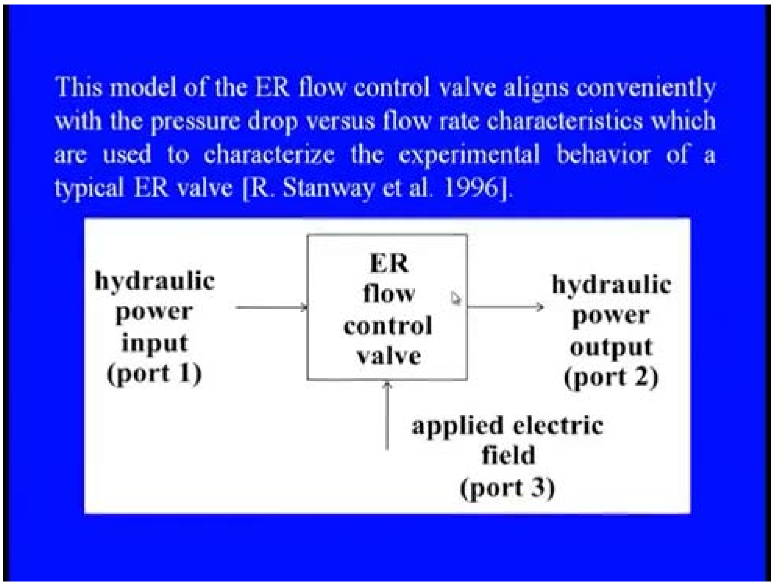

So, you can see that the model of ER flow control valve, which simply aligns conventionally with the pressure drop. We can simply you know like make a characteristic between that what the pressure drops, and the corresponding flow rate characteristics are there. So, as you know like the these characteristics been exhibited in one of the paper Stanway in 1996, we can see that we have the port 1, where the hydraulic power inputs are there, at port 2 we have the hydraulic power output. And at port 3, we have the applied electric field, so entire electric field control valve mechanism can be straightaway work together under these three ports.

And when you know like these things can happen, we can say that, the hydraulic power input, which is you know like being applied at the port one. The corresponding power output which is nothing but the product of outlet pressure, and the flow rate can be taken at port 2. And whatever the control which is being required, in the form of applied electric field, which you know like influence the fluid resistance can be straightaway acted under the control unit.

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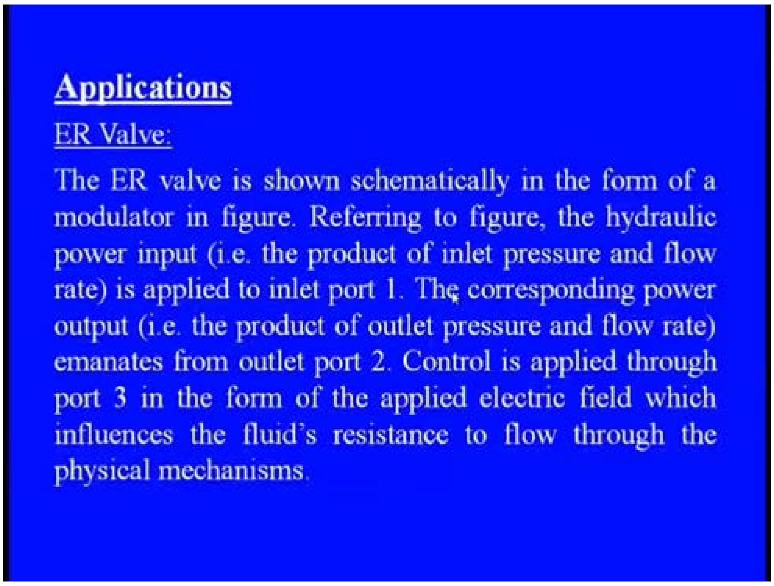

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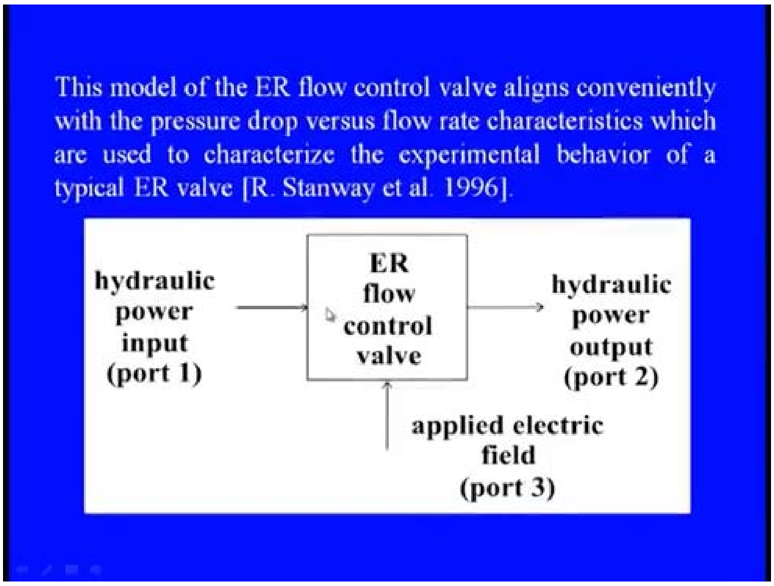

So, this is you see a scheme in which we can say that, the entire control features are being there according to the required, we can say electric field.

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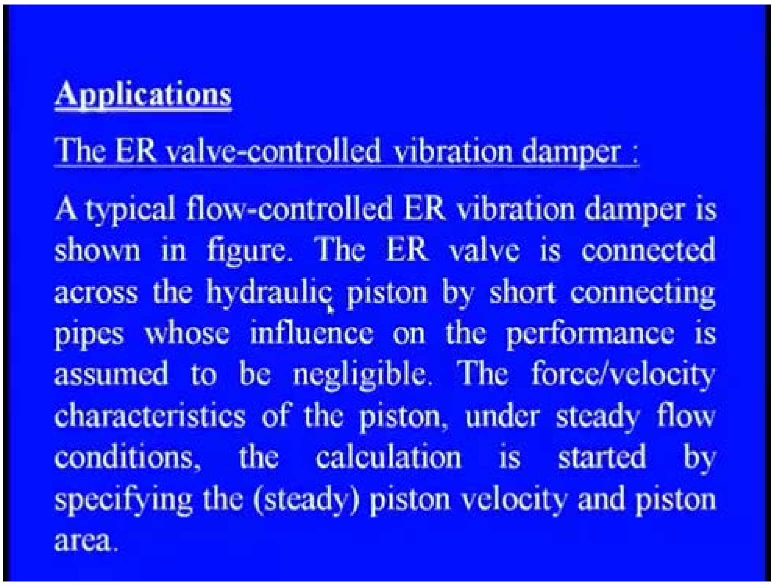

Even, we can say that the ER valve, which can control the vibration damper, we can control the vibration according to the damper feature, so typical flow control ER vibration damper can be straightaway connected to the hydraulic piston by the short. We can say connecting pipe, whose influence on the performance can be we can say that you know like it is not, so significant.

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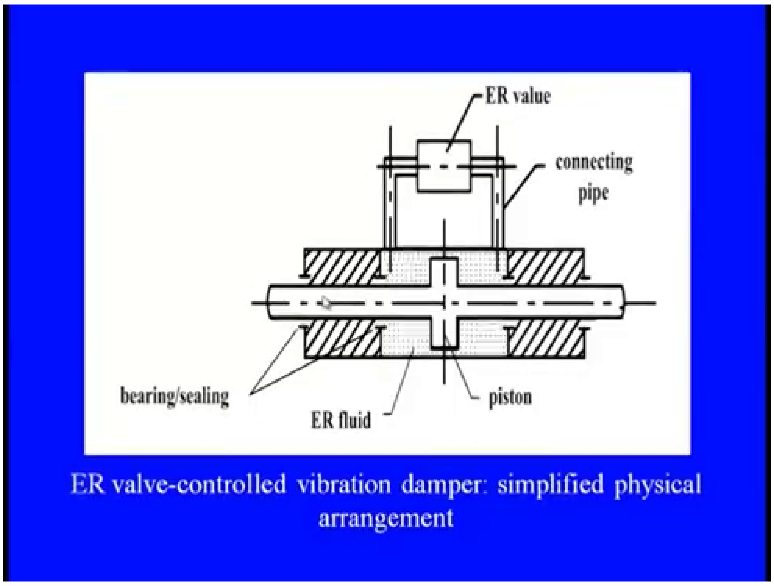

ER valve-controlled vibration damper: simplified physical arrangement

And the force or velocity characteristic of the piston, when they are just moving under steady flow conditions, we can simply you know like featured out, and the calculation we can say under the you know like the steady motion of piston. And these we can say you know like the piston velocity, and the area can be immediately formulated out and can be framed easily.

So, this is what you see the piston feature you see where you see the ER valves are there, this is what my ER electro-rheological fluid and the pistons are being moving towards that. And whatever the connecting part through, which you see you know like the ER which is connecting the ER valve, and this is simply showing that you see how the passes are being forming. And then how we can control the entire device means using the vibration damper, and how they can be act towards the damping or we can say the viscoelastic feature, with the things are being required.

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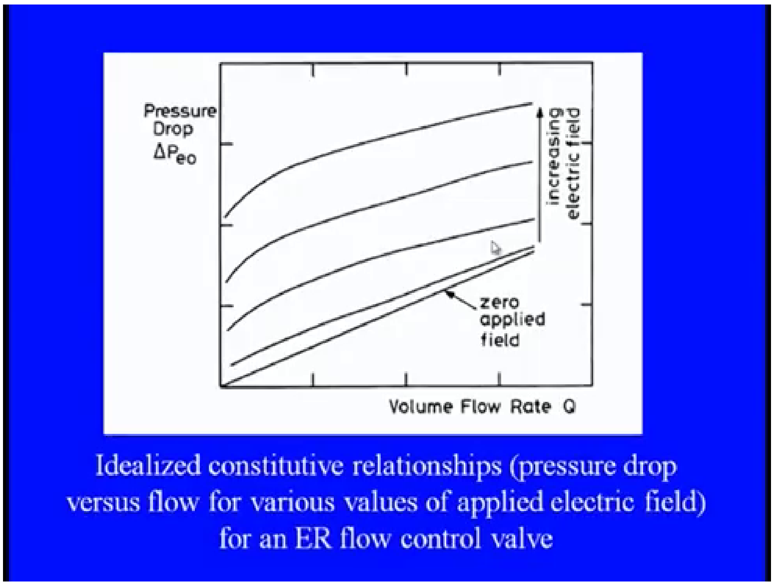

And when we just want to show the relations between the pressure drop, and the you know like the flow versus applied electric field in the ER flow control valve, we can see that when the flow rate is being high the pressure drop is also being increasing. And then the you know like the electric field is also being increased there itself, so when we have a 0, the this applied field. We know that this stress shows the linear relationship between the pressure drop and the volume flow rate, under that and when you see we are changing, there is a clear non-linear variation in between these parts even when we increase the electric field applications.

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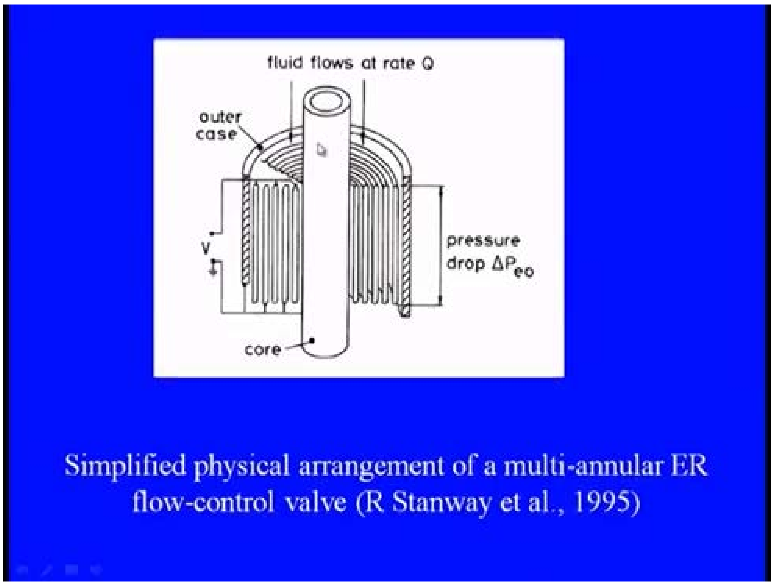

And when we just want to see the multi annular, this flow control valve, you can see that these are all you see that the annular part, and then the flows are being there from that. And these pressure drop, which is being there in between that part, we can simply gather and we can find by increasing the electric field through this core, we can see that how the variations are there between the pressure drop and the volume rate.

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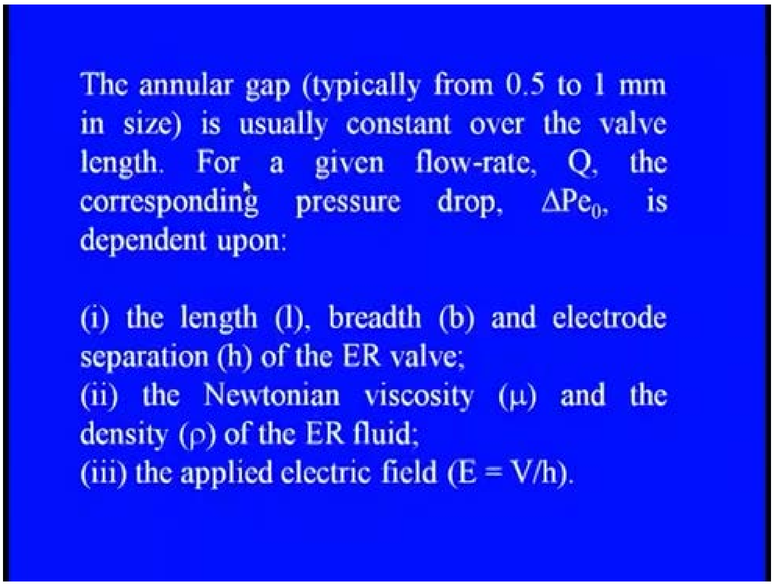

So, we know that annular gap is always in between one millimeter to 0.5, and it is always being constant according to that, so for given discharge we can simply find what the you know like the corresponding pressure drops are there. And it is according to the length the breadth or the electric separation of electric valve, first it is depending this second it is depending on what is a newtonian viscosity, and the density of the ER fluid, and third which is very important the strength of the applied electric field.

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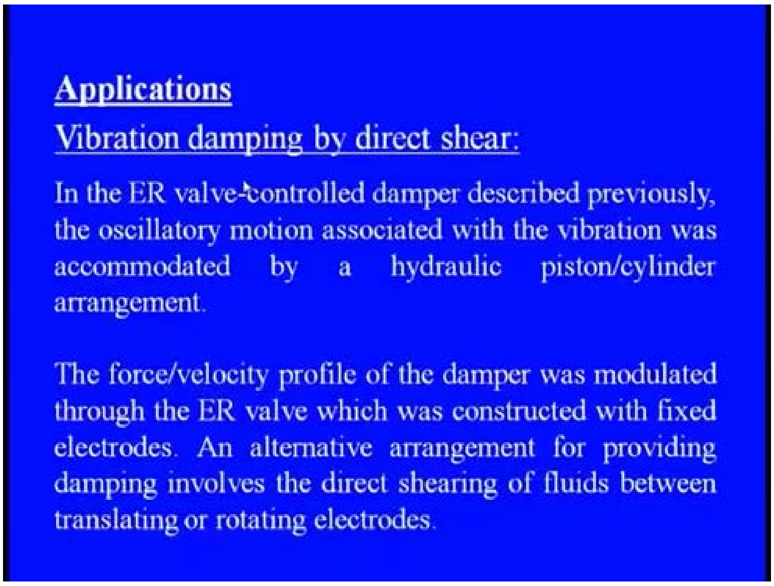

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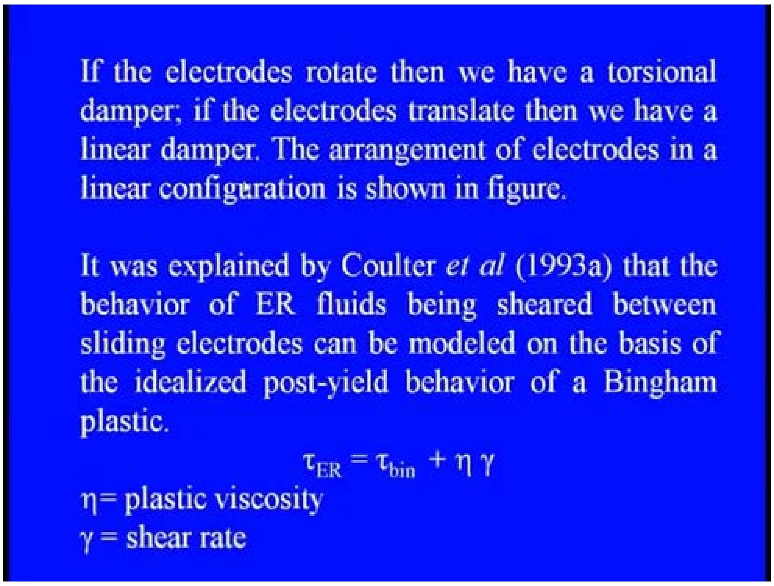

So, you see here the vibration damping can be get using this direct shear mode, when the you know like the shearing features are there, it can straightaway increase the solid form of that. And then the solid form of between the particle, as they have been channeled out and then they can be simply framed, this shearing part of the fluid between the translating and the rotating electrodes.

If you want to find out if the electrodes are being rotating, then we can say that we have a torsional damper, and if the electrode are just translating, we can say that we have the linear damper. And we can simply you know like exhibit the relation, as we know that the yield behavior of these ER fluids are the Bingham plastics. So, we can say the tau ER means the plastic this the shear stress of the ER fluid is nothing but the minimum shear stress, which is being there plus eta into gamma, where the plasticity and the shear rate is being formed together.

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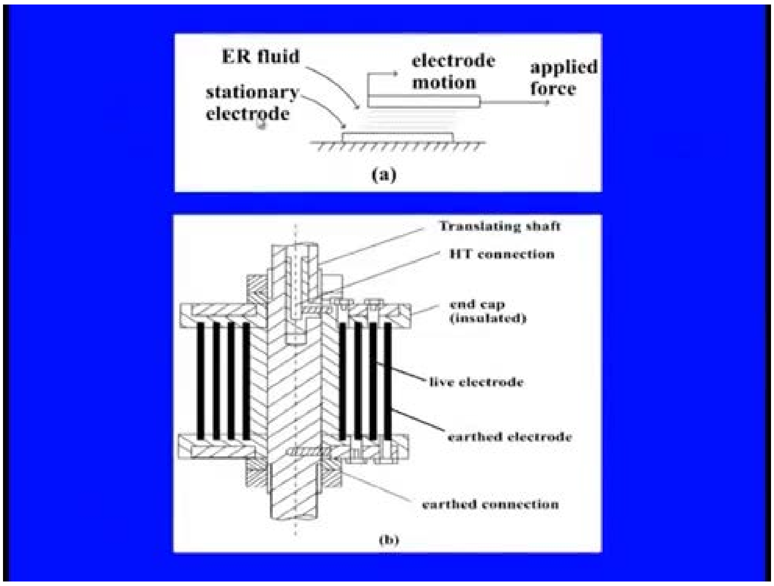

So, we can say that this is what you see the shearing modes are there, when the electrode motions are there according to the applied force, and the in between the this is stationary electrode, and the moving electrode the ER fluid are being just sheared out. Even, we can see in this other part that, you see here when we have these electrodes in between you see through, which we are applying the electric field. And in this particular part, where you see we have the entire, these you know like these fluid particles they have been just shearing in this way.

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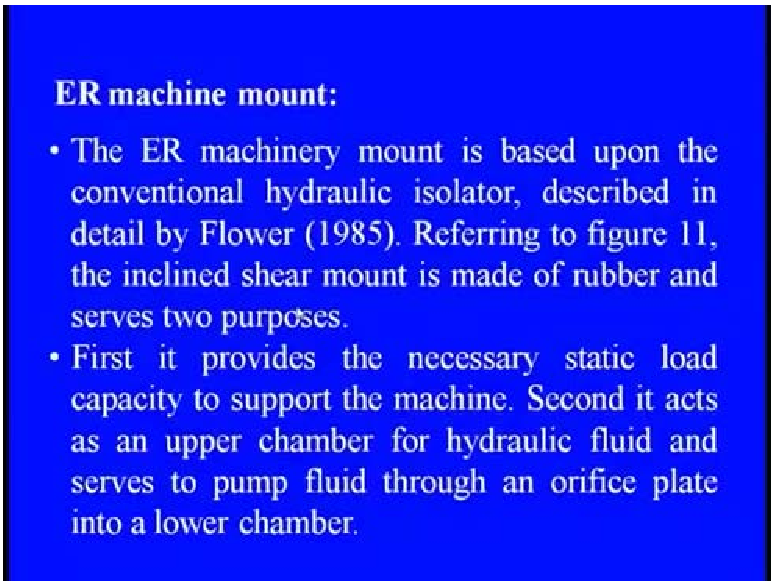

So, the last part in this is the ER machine mount, in which you see here we can say that the electro-rheological machinery mount is based upon, just the this hydraulic isolator. So, first it is just a providing the necessary static load capacity, to support the machine, and second it is also acting on the upper chamber for hydraulic fluid, and it just serves to you know like pump for fluid through the orifice plate at into the lowest chamber.

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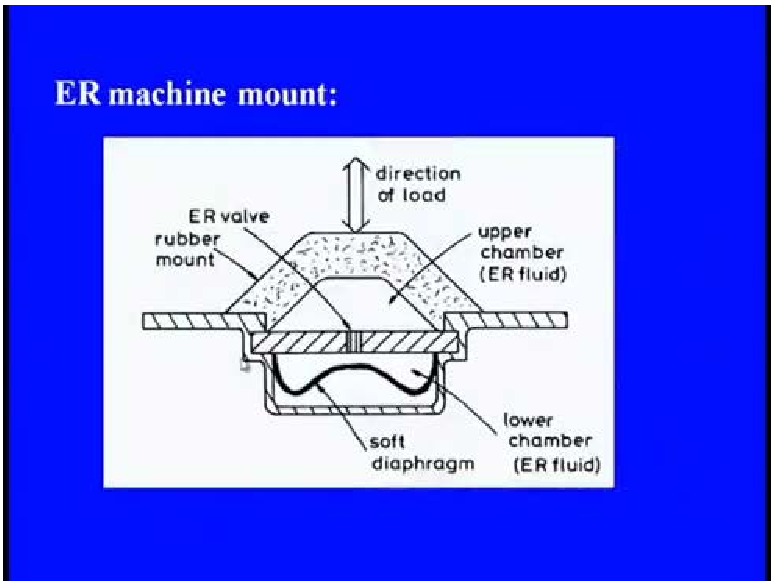

So, this is what it is there, the ER fluids are there in between this, and you see on top of that we can say that you know like we have the rubber feature, which is being mounted there. And in the upper field also these ER fluids are being there, so whatever the direction of loads are there, they can provide a better this machine mounting.

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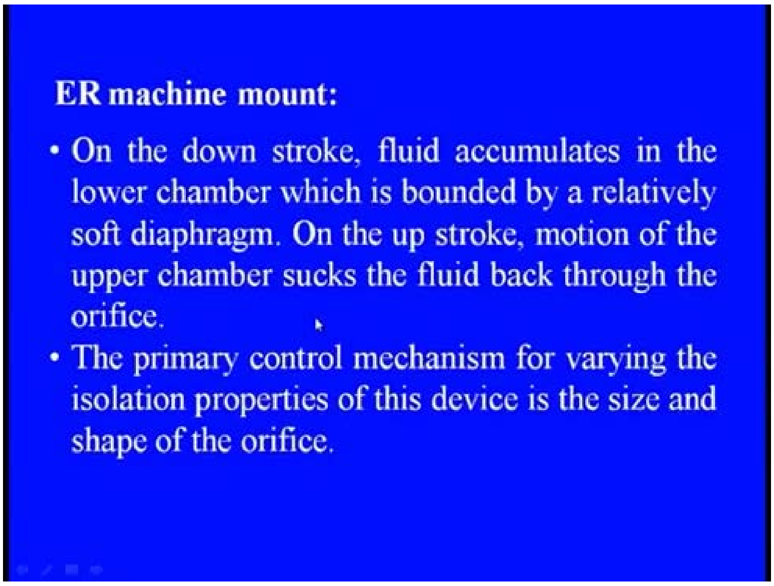

So, you see here we can say that the for this ER fluid, they the primary control mechanism in this for varying the isolation properties of this device. In the main form of the size and shape of the orifice, through which you see here we can control the entire motion of the machine mounting feature on that.

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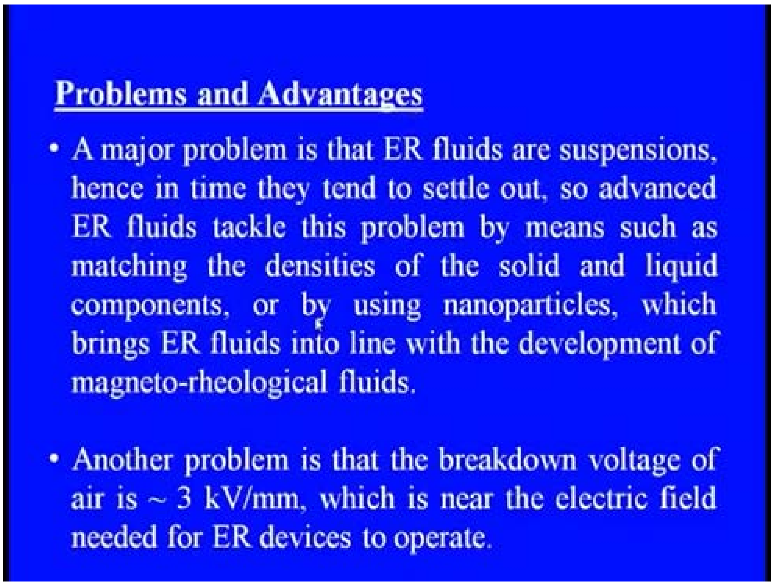

And this is a great application, when we are just going with this, lastly if you are talking the major problem in the ER fluid are the suspension, hence you know like in time they tend to settle down. So, the advanced this ER fluid tackles this problem by means that, as you know like they are matching the densities of the solid and liquid components, or by using the nanoparticles, which brings ER fluid into line with the development of magnetorheological fluids. And another problem in this is the breakdown voltage of the air as three kilovolt per millimeter, which is near the electric field needed for ER devices to operate.

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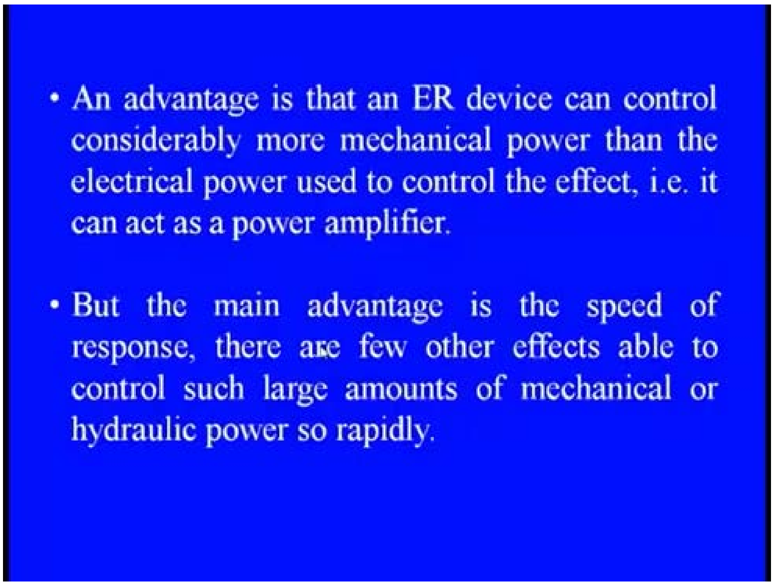

So, you see here we need to modify this characteristic, otherwise you see you know like we are always having the breakdown voltage in these featured, but there are advantage of electric field. As, they can control considerably more mechanical power than the electric power, when they are using as the controlling effect, you see here means we can say when they are acting as a power amplifier. And also you see here the speed of the response, when the few other effects are being able to control the large amount of mechanical or hydraulic power can be rapidly, you know like applied to these things and we can have a the response in a very speedy manner.

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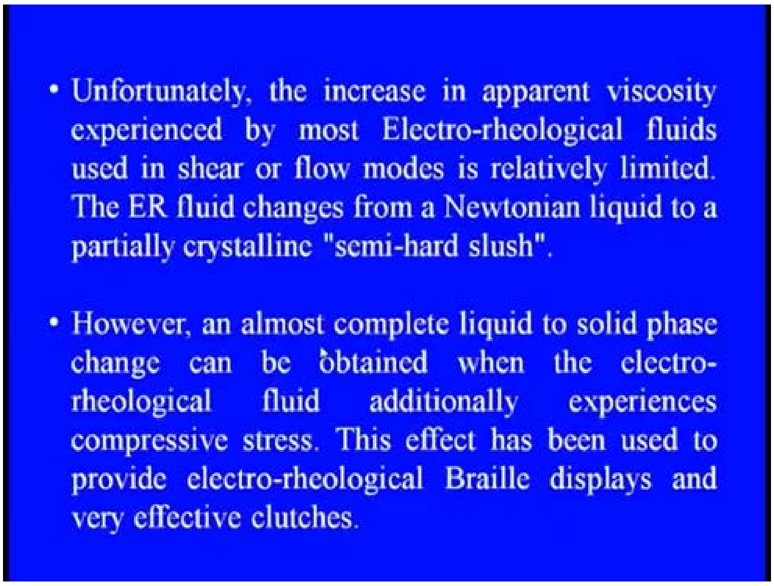

So, this is where you see you know like we can say, when we are just increasing the electric field, the apparent viscosities also experienced by the most ER fluids, which are being used in the shear or any other flow modes. And that is part is very limited in this, because the ER fluid changes from Newtonian liquid, to partly we can say that you know like the crystalline feature a semi hard slush.

So, we need to check it out that when an almost liquid to solid phase changes, which can be obtained when electro-rheological fluid, additionally experience is an a compressive stresses. So, we can use this effect just to provide the electro-rheological Braille displays or we can say very effective clutches, where the things are being you know like used based on the ER fluids.

So, this is a brief discussion about the ER fluids, still you see the huge research is going on about the main characterization, and whatever the drawbacks are there in that can be straightaway reform there. So, in the next lecture now, we are going to discuss about the basic feature of the magnetorheological fluid, what is the basic mechanism, and how we can adopt this as the vibration control device there.

Thank you.