Tribology

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Lecture No. # 11
Lubrication and Lubricants

Welcome to 11th lecture of video course on Tribology. The topic of this course is lubrication and lubricants. We have studied friction mechanisms and wear mechanisms; if both are harmful, if we do not desire friction, we do not desire wear they may be another number of possible solutions. But one solution is a lubrication, if you provide lubrication, then wear will come down and reduce friction will reduce. That is why when we define lubrication, we say that lubrication is a process, is a mechanism to reduce friction and wear between relatively moving contacts or tribopear.

And when we define lubricant, we say it is a substance, which is interposed between two substances or two solid surfaces, so that shearing strength of the interphase is reduced friction is reduced subsequently wear is reduced. I want to give more emphasis on the wear decrease or reduction in wear rate compared to reduction in friction. As it was pointed in earlier lecture wear reduction is much more compared to friction reduction friction reduction can be hundred times, but wear reduction can be ten thousand times using proper lubrication mechanism.

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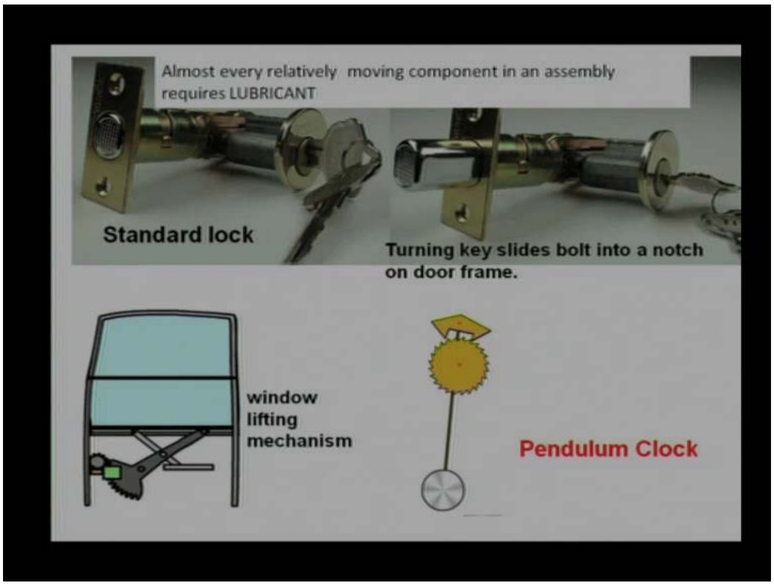

It is a really an interesting and we have number of application, where the lubrication is required. You can see this picture this is of the very, very common example. It is a standard lock mechanism, we have key over here there will be bolt connection having a some geometry of course, it is not a true threaded bolt. But we can say it is a bolt, because, it gets engaged in the door slot and locks the door here we can point, if there is a on and off key, there will be, this component or this bolt will be reciprocating.

If there is a reciprocatation, reciprocating motion than friction will be there. And if you do not provide proper lubrication or we do not provide lubrication layer on that or proper coating on the surface. Then there will be high friction and jamming action will occur it will not work satisfactorily for a longer time.

Similarly, there is another mechanism and we call as a window lifting mechanism. Window pan is generally lifted, if it is a power drive than we use a gear mechanism. And generally, gear mechanism in this case particularly, it is a motor small size motor is engaged with a complete gear. And the sector gear is moved with this spur gear or a mom gear pair, which ever engagement is there. As there is again tribo surface for satisfactory work, we will be requiring lubrication either solid lubricant, liquid lubricant or semi solid lubricant, so that it can function properly without much restriction or jumping mechanisms.

So, another common example is a pendulum clock. We know the pendulum clock has a relative motion, as well as surface to surface contact it requires a lubricant to work smoothly. If we do not provide lubricant again it will not work and it will consume more power compare to it is expected.

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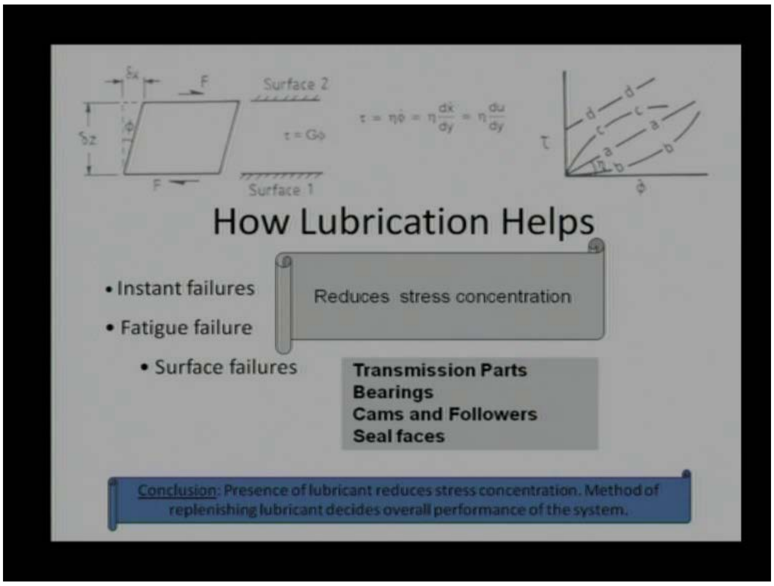

The question comes, how lubrication really helps? It was earlier mentioned it reduces the friction it reduces the wear, but, in addition to that there are couple of more advantages of lubrication. We said many times it reduces the failure possibility due to the certain change in load certain, change in lubrication conditions, certain change in misalignment. If there is a some lubricant, which is stacked to the surface it will work satisfactorily for the fraction of second or transient time.

In addition to that we can say if there is a proper lubrication. It reduces the stress concentration. If there is a irregular surface will be filled with the lubricant and that will reduce unevenness it will reduce stress concentration. Many times we have a we know that stress concentration factor goes up to 1.7, 1.8 that means is (( )) pride in lubrication mechanism, we are going to get benefit of 40 to 50 percent on that.

In last lecture we studied about the camp failure mechanism or a camp failure analysis, where the surface failure, surface fatigue was emphasized. If we provide a lubricant that surface fatigue failure will reduce. It was also mentioned that if we provide a lubricant coefficient of friction will reduce sliding will reduce and that will reduce force requires in tangential direction. If the force required in tangential direction is reducer fatigue failure will reduce or we say that life will be a slightly on a higher side or may be greatly on higher side, depend on the lubrication mechanism which we are providing.

And this stress concentration factor which is been emphasized is common in number of devises like a transmission parts. If we provide a lubricant, if we do proper lubrication transmission part stress concentration will reduce. Similarly, bearings some micro pitches generated, or is widely irregular surface that can be reduce the stress concentration can be reduced. Similarly, cam follower mechanism, which has a relative motion as well as reciprocating motion, rotational as well as the reciprocating motion. That stress concentration factor will reduce in that.

In addition some time we required sealed phases with a solid lubricant to give mechanical contact. But lubricates that is the way the friction and wear is reduced, in that case the solid lubrication is used, to compare lubrication mechanism with a solid lubricant solid mechanics. We can take this example you can there are two surfaces surface one and surface two subjected to tangential forces.

If the surface one and surface two are subjected to tangential force and they are interlinked they are linked one way another way. Then there will be some sought of shared deformation the shared deformation is generally given in angular way that 5 or it can be linear term sigma or say delta x. If you want to represent in terms of a stress you can say that tow is equal to g into 5. Here g is a shared modulus, shared modulus is generally given in terms for giga Pascal for most of the matter is a giga Pascal or polymers may turn out to be mega Pascal. But, if the shared modulus is reduced the shared stress is going to reduce for the share same share deformation.

So, that is the advantages, if I reduce this constant share modulus to the eta, which is viscosity in this case, am taking example of liquid and assuming the liquid is a non Newtonian liquid in that case non Newtonian liquid case. Tow with a shared stress can be given as a viscosity into share rate.

The share rate is expressed in terms of velocity gradient. Now, if I compare g verses eta, g is a modulus of rigidity or share modulus expressed in terms of giga pascal for most of the material. While eta is generally expressed in terms of mille Pascal second, is almost a difference of thousand or more. That means, whatever the share stress generated in liquid will be lesser than 0.1 percent compared to the shared stress generated in solids.

And we know if the share stress generation is much lesser or share resistance is much lesser interphases will glide will move smoothly. It will reduce coefficient of friction and subsequently it will reduce the wear, or in other word. Whenever we are providing lubrication adhesive wear is going to come to the almost zero value or adhesive coefficient of friction will come down to the zero. I cannot say for other mechanisms for (( )) mechanism. Yes, it will reduce, but come to the zero level of convergent case, it will reduce friction as well as wear will reduce, but, necessary it comes to the zero.

However, if we are providing a lubrication and proper lubrication adhesive wear mechanism will come down to zero. On the (( )) wear mechanism will work. If there is no complete separation between solids, if there is a complete separation or lubricant is able to provide thick lubrication completely separating two surfaces. Then that case wear will be zero that is required for most of the applications.

We discussed here share stress relation for Newtonian liquid, but if we think about the non Newtonian liquid. We can say behavior may be expressed as a b v. This graph is a shared stress verses share rate, this graph shows clearly the domination of the five compared to tow.

While this x can, this there are liquid also which will show the behavior like c c, c c curve and there are few liquids or the semi solid. Let me take example of the grease they will show behavior initially they will not deform at all. If the share force is applied and once it is applied, it will show a Newtonian behavior. A typical Bingham liquid what we say use a term is with a Bingham liquid behaves like that there will not be any share deformation initially.

And once the share deformation starts then it will work as Newtonian liquid. So, we treat this kind, of the liquid as the semi solid liquid. It is showing a behavior like solid initially and subsequently it is turning out to be liquid. So, we can say we can conclude from this slide .We say that presence of lubricant reduces the stress concentration factor. That is a substantial as a very good factor for us, a method of the replenishing the lubricant beside overall performance. It is not only the providing lubricant at one instant. It is the continuous phenomena and, if lubricant is wiped out is squeeze out, then we need to again and again bring the lubricant at the inter phase.

So, that is important and that is why the lubrication mechanism or study of lubrication mechanism is very essential. There is not only the first side you provide a lubricant and you will say that lubricant will remain their forever. We know share stress lubricant reduce the share stress, but, along with the shearing this lubricant also will be wiped out.

Once it is wiped out then again the again share stress will increase, or more force will require. So, that is why we required again and again to replenish the lubricant at the inter phases. That is the important that is why the lubrication mechanisms are important.

We will take a few examples to understand, what do we expect from a lubricant naturally we are going to spend some money on lubricant and, if you are studying lubrication mechanism and the way lubricant need to be replenished. Then question comes how much cost will be involved will it that be justified compared to without lubricant. So, we can believe that yeah there will be some expectation, if we keep some expectation and lubricant is full filling. This expectation then cost may not matter that much.

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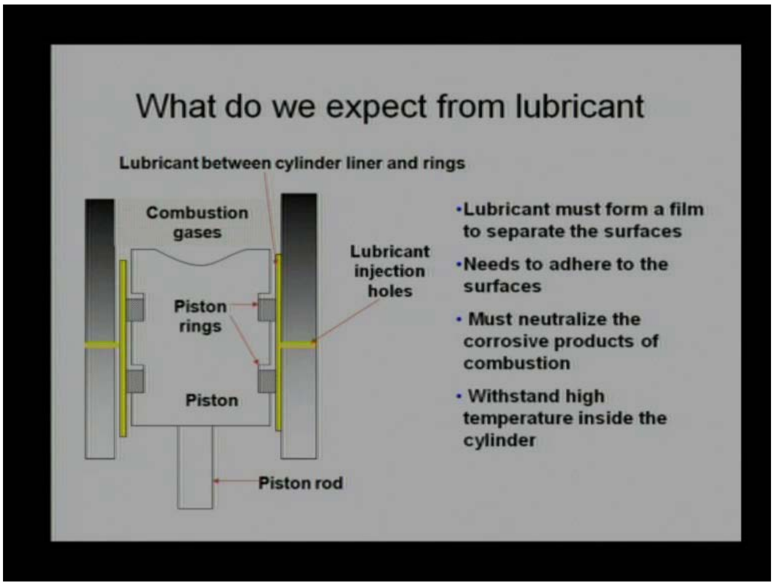

Let us take an example of icy engine piston and ring lubrication mechanism there is a cylinder liner there are pistons, piston rings and there is a piston. Now, we know the piston has to reciprocate, for the compression for the expansion and there will be combustion gasses towards the cylinder side or where the fuel and air mixture is abound and gives a spark get the expansion stroke. And there are some lubrication holes not necessary always cylinder has to have a lubricating holes. There may be number of other provisions, we can provide lubrication through piston road also.

So, number of lubrication mechanisms, but for convenience we have just shown that lubricating holes are present in cylinder liners. When we are providing the lubricant, what are the requirements? We say that lubricant must form a film liquid film to separate the surfaces that means, piston should not touch cylinder liner, or piston ring should not touch the cylinder liner.

There will be solid contact there will be higher friction. And icy engine is primarily used for the power generation, if generates some power may be say x unit and we know because of the friction, we are consuming power by point to 0.3, 0.4 x, that means, we need profit will be only point six unit or point seven x unit. So, that is not desirable, lesser the friction better the results and due to for that reason, we want to separate the metal, metal contact as far as possible. If it is not possible then we can think about the material, which are showing very low coefficient of friction in the absence of lubricant.

So, first requirement from icy engine lubrication mechanism is that lubricant must form a film to separate the surfaces. Second is that forming and completely separating is the one issue. But, it should adhere to the surface is more like a oiliness, the way we apply oil on our hairs. So, that they get separated on there is a thin lubricant layer on hair. Similarly, we want a thin lubricant layer always to be on a metal surface. So, that there should not be direct contact. You get two things, we are thinking about attachment of a thin lubricant layer. As well as separations of the two metal surfaces two things are different we will be discussing this in detail.

And in addition to this two requirements, there is another additional requirement is that this lubricant must neutralize. The corrosive product, which are produced due to combustion process or some gasses, which are produced and when they get mixed with lubricant they mix acids like a choleric acid. That will create a corrosive environment and will corrode the parts or machine part or icy engine parts.

So, we need to have a lubricant, which neutralize this corrosive product, which bring them either they is more like a give a cage to the corrosive product. So, the corrosive product is not free and to disturb the other icy engine parts.

And finally comes, you need to with stand high temperature in now icy engine temperature minimum temperature will be around 90 degree to 95 degree centigrade. And it can reach to the 150, 160 degree centigrade. So, lubricant needs to sustain this high temperature without failure, we should full fills the function without failure at high temperature. So, these are requirements should make a film attached formally with a surface neutralize, the corrosive product or similar kind of products, which are going to harm icy engine and should be able to show form performance functionality at high temperature.

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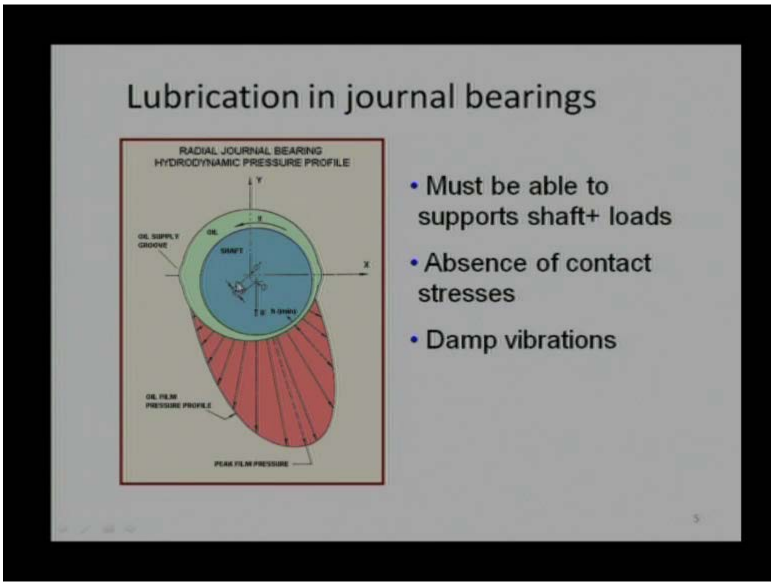

Let us take another example is the simple journal bearing. Journal bearing we say the one of the cheapest machine support. That is one of the economic machine support, it can be made in any work shop without much problem and this bearing has a requirement of the wage action. There should be always extensity to support the load, but, extensity should not be equal to 1.

It should not touch the surface of the bearing or we say that shaft should not touch the surface of bearing. There should be always some thickness and that thickness should be greater than surface softnesses. It should not happen that surface softness and h are almost the same order in that b x case this bearing will not work nicely.

In addition, we this figure shows a pressure profile you think, if we do not provide the lubrication, what will happen this shaft will come and collide or maybe say in contact with the bearing surface. And that contact because both are the, these are the cylindrical piece bearing is also cylindrical piece.

So, when they come in touch without load, there will be only line contact. If we apply a load along with the relative velocity it is going to subjected to contact stress. The way we explode in camp follower mechanism. So, to avoid that, if you are providing a lubricant you can see the pressure profile is generated instead of localized contact, localized stresses very high value stresses. Now, stresses are getting distributed uniformly. So, instead of 5 degree or 10 degree contact it is going more than 120 degree contact instead of 5 degree contact. If 120 degree stress concentration is decreasing substantially contact stresses are decreasing substantially. Here you can say there is almost absence of contact stresses. There may possibility of the initial or some condition, some contact is possible, but, 99 percent it can be avoided.

And what is the additional requirement for the lubricant. We say that it should support the shaft plus load. Shaft is a dead weight of the shaft whatever the, another element imparting the load on the shaft or transmitting the load on shaft. That should be supported by this bearing this lubricant, which is used for the bearing.

In addition there is one requirement it should dam the vibration. It needs to have dumping qualities it need to have dumping properties. So, from this point of view from bearing point of view what we require from lubricant it should support the load. That means, it should make as thick film lubrication without failure it there should not be any contact stresses, whatever the situation and finally, it should come should be able to dump the vibration. We are not counting here the temperature aspect as such because that will depend on the application. If the, it is used in compressor temperature will be different, but, use in icy engine temperature will be different.

So, that temperature requirement will come along with applications. But, in absolute sense or just from the bearing point of view these requirements are sufficient. So, if lubricant is able to satisfy this requirement.

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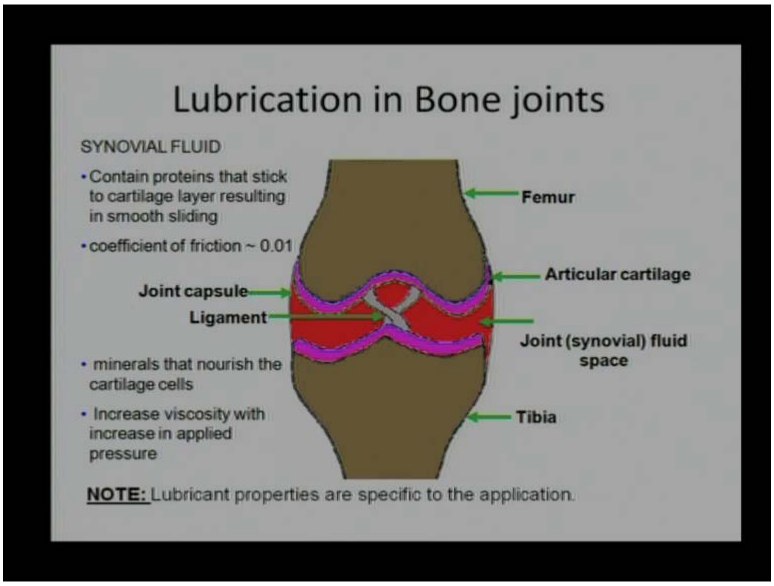

You will be this is one of the common example of our human body joints you say whenever there are two bones in the relative motion, the joint will be made and that joint required lubrication. And we use a lubricant here as a synovial fluid is a more like a process fluid. Or this gives a opportunity the wherever the liquid is flowing that can be utilized as a lubricant by just giving some attitudes or some adding some substances to that.

So, what is in this joint is femur shown, tibia is shown and there is a censorial fluid in this space. If there is a squeezing action if the motion relative motion there is a possibility of this liquid coming out and going back.

So, that require some property, we say that this liquid need to contain proteins. This is no where related to lubrication, but, it requires. Proteins that stick to the cartilage layer resulting in smooth slides. It requires proteins, one way and they are acting as also boundary attitudes to provide a smooth friction or smooth sliding low friction.

When we talking about low friction, we are talking about the order of like 0.01, coefficient of friction that is, substantially low very low value. In addition to that it this cartilage cells should not get damaged. That is why this censorial fluid need to have minerals. So, that can nourish the cartilage cells.

Finally, need to have pressure viscosity coefficient, substantial coefficient. What we are saying that when then pressure is increase. This liquid should get compressed if the liquid is getting compressed. It will can sustain more and more stresses or its viscosity will increase and if viscosity increases, load carrying capacity will increase. And we have experienced by changing pressure from x unit to the 1000 x unit viscosity also changes, may be from x unit to 21 x units. Changing viscosity is essential increase in viscosity is essential, whenever there is high contact or high load is applied which is inducing high contact stresses. So, from this point of view we can say, if we are using lubrication mechanism for the both joints it requires proteins, it requires minerals to have viscosity coefficient, which is allowing viscosity to increase with the pressure.

And from this three example I can we have more number of, we have number of examples, but, just for our purpose, we are using only three examples, so that we can initiate discussion on this. We say that lubricant properties are specific to the application they are related to the application. It is not that we can go ahead with generalized lubricant property pick up any lubricant use anywhere. And we will get solution its nothing like that you need to understand what application is? What are the requirements and apply lubricant accordingly?

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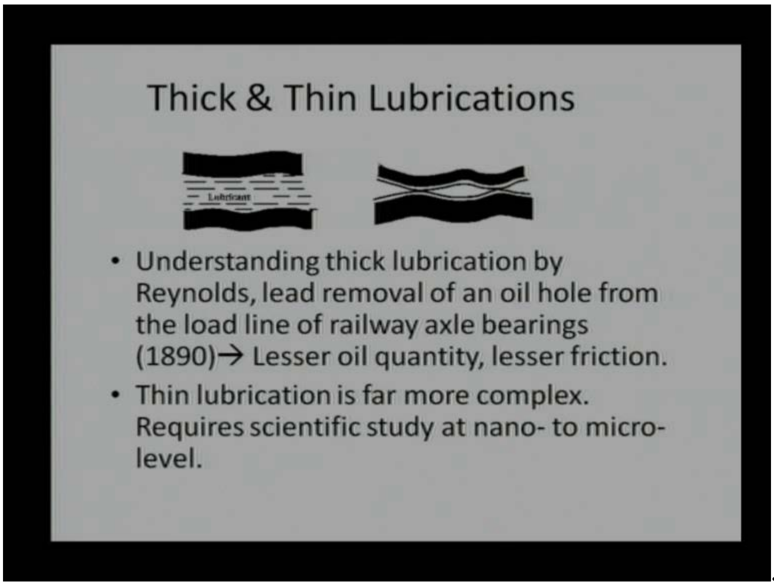

For convenience, we can divide this lubrication mechanism in two broad categories, what we call as a thick lubrication and thin lubrication. These pictures or this sketches are clearly indicating this results say the solid surface 1, solid surface 2 almost equal thickness is a liquid lubricant also. You can say that there is a thickness of the solid is thickness of solid and this is thick lubrication completely separated nowhere related.

So, materials whatever the material, we choose for surface one surface two. It is not going to affect the results. At least at the tribology level at least at the friction point of view or from friction and wear point of view.

However, there is another thin lubrication mechanism what we are saying that this is thin lubrication mechanism. The surface one and surface two is the thin lubricant layer which is attached to the surface. Good enough to separate the surfaces, but, not good enough to completely separate it.

Surface or lubricant layer which is coming in this configuration is able to reduce coefficient of friction. And reduce the wear rate also, but, there is a possibility of detachment and engagement of the, this lubricant layer that will be dynamic process. This lubricant layer gets attached and detached also. It will be continued because there is a sliding and a there is a need, there need to be a mechanism, which will again come bring back the lubricant layer on the surface.

So, this kind of mechanism will get disturbed, if there is a change in the condition. If we are increasing the load naturally this lubricant layer need to be changed or material, which is required that need to be changed. We are increasing temperature there is a possibility of the fluidity of this lubricant layer that will wipe of or wipe out or squeeze out easily. So, it is very sensitive this kind of lubrication mechanism is sensitive towards the operating condition increase in a temperature, increase in a pressure or hard asperities which are coming into contact that will disturb the lubrication mechanism.

So, as far as possible we should avoid it, we should come to the solution. This is much more (( )) system, however, optimization says that lesser space is always preferable. We need to go ahead with the micron size components or nano size components. So, in that case we require this kind of mechanism. That is why we say that when we design a hard disk drive, where the space is the major concentration in that situation, we need to reduce this lubricant thickness may be stay out of 10 nanometer or 3 to 10 nanometer much lesser than 10 nanometer.

When we try to understand the thick and thin lubrication mechanism, we say that for thick lubrication mechanism, we need to use a Reynolds theory. Reynolds somewhere in 1886 published in a scientific research paper after getting very good experimental readings and explaining those readings. I mentioned that, if we rotate shaft in one of the bearing surface then there is a possibility of pressure generation.

And based on that observation he could develop a complete scientific theory explain the theory, why it is happening. And we need to use that theory to explain the thick lubrication mechanism, what will be advisable over for overall system design.

If I go ahead with this theory, we say that thicker and thicker lubrication will not be very useful. If I keep on increasing the thickness of the lubricant it will not be very advantages to us. Lesser quantity is causing lesser friction of course, there is no wear this is the mechanism where there will not be any wear, but, there will be only friction. If you provide more and more lubricant, there will be more and more friction.

So, to find out what should be the optimum value of lubricant thickness, we need to use a Reynolds theory we need to use this kind of solution. Coming to the thin lubrication mechanism as I mentioned earlier this is very, very sensitive to environmental condition. So, it is for complex. It requires a huge number of experiments to come up with any definite solution.

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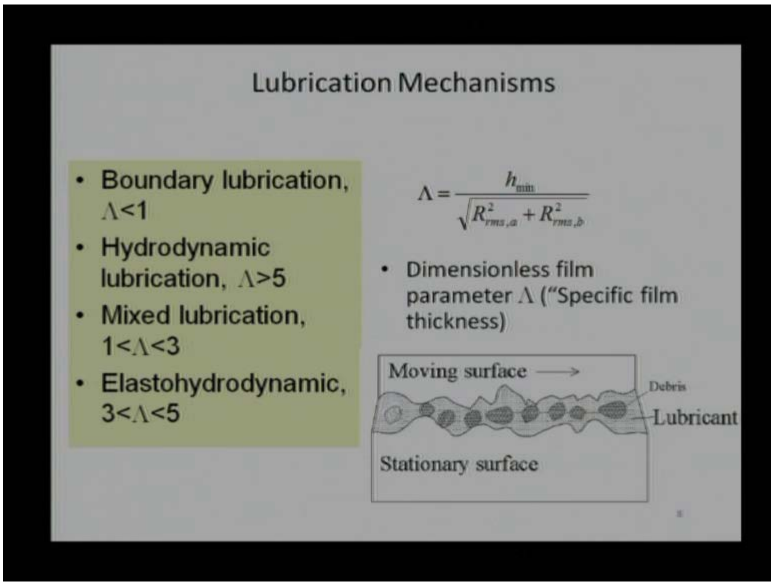

And because, scientific studies are the nano, micro to nano will even the lesser than nano level we talk about (( )) level in this case. For convenience, we can relate all this lubrication mechanism with one parameter it is called lambda or capital lambda. As it was mentioned in 2nd lecture, this lambda is a ratio of film thickness by composite surface softness. It is also known as a specific film thickness parameter.

And what we call a thin lubrication mechanism can be coated if lambda is lesser than one. We can say thick lubrication mechanism, when the lambda is greater than 5. But, there is a possibility intermediate stage, what we say the mixed lubrication and we say the Elastrohydrodynamic lubrication. In case of mixed lubrication, we use a both the boundary lubrication as well as the hydro dynamic theory.

Coming to the Elastrohydrodynamic lubrication, we use hydro dynamic lubrication, as well as elastic deformation. And we need to make sure that surface softness is not coming in the picture. Otherwise we need to analyze and find Elastrohydrodynamic lubrication mechanism is without aspartic contacts.

As previously it was mentioned that, if there is a wear generation or particles coming from outside, then quite possible hydrodynamic lubrication mechanism may turn out to be a mixed lubrication mechanism, because of the particle occupying this space reducing the effective film thickness. That is why the from e h e l will moved to the mixed film lubrication. So, we need to keep all the quarries ready, whenever the situation comes we need to use that theory and combination of theories.

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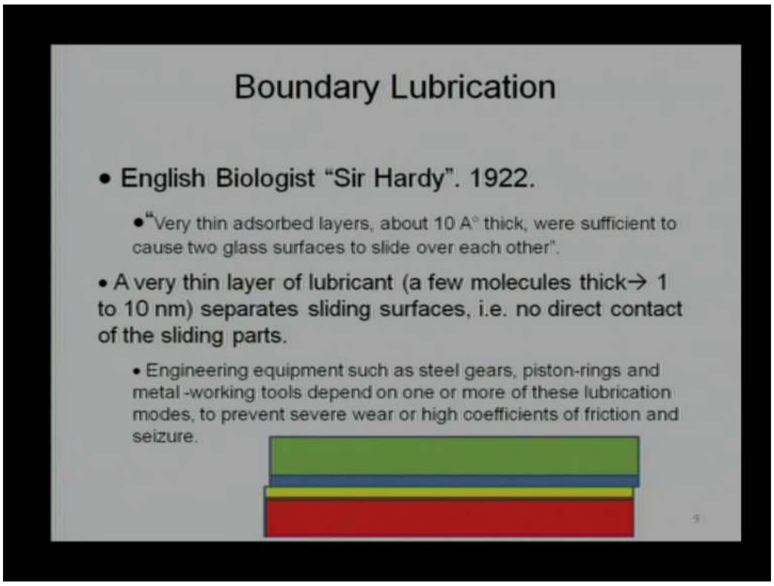

So, that gets a overall possible or get a solution. Let us start with a boundary lubrication mechanism; we say that this term was coined by sir Hardy somewhere in 1922. Interesting this guy was a biologist. He was from biology background what he coded. It is a very thin absorbed layers about 10 angstroms thick was sufficient to cause two glass surfaces to slide over one over each other one on other.

He was mentioning about thickness the 10 angstrom that is very very low thickness and he could prove that sliding is much smoother compared to without this thickness level. An interesting thing is that, it has been observed by number of researches, that even this thin layer is able to separate contacting surfaces. There will not be any metal to metal contact even with layer thickness up to 10 nano meter naturally.

We are talking about the surface softness, but, above that you could layer such a way, we could boundary lubricant layer such a way that surface softness is not directly coming to picture. Wherever, surface touch wherever respiratory touches. It will not touch the other metal surface directly. It will touching with supper facial layer, that will be boundary attitude layer.

What we are trying to convey something like that assume that there is a green box. We say the substance one or surface one the red color box. Substance one or material one or surface one, the surface two and then there is a thin layer on the red the color box. This thin yellow color is a boundary layer and shows clearly, there is the clearly separating the red color from the green color. Same thing we are depositing also earlier on the blue color or blue color layer on green color layer.

So, there is a possibility that two surfaces can be completely separated, but, how the question is always difficult, but these situations are required by enlarge for all the machine components. Almost every machine elements require this kind of a layer, if there is a relative motion of that component.

We say engineering equipment such as a steel gears, piston rings, and metal working tools. We are talking about the steel surface depends on one or more of this lubrication modes, whatever the lubrication mode are the we are talking about the boundary lubrication, boundary lubrication itself has a two mode. What we call a physical absorption and chemical absorption. So, whichever mode that is required for this kind of a elements, machine elements to prevent severe wear or high coefficient of friction in extreme case. As I mentioned adhesive wear that extreme cases are seizure and seizure should be avoided as far as possible.

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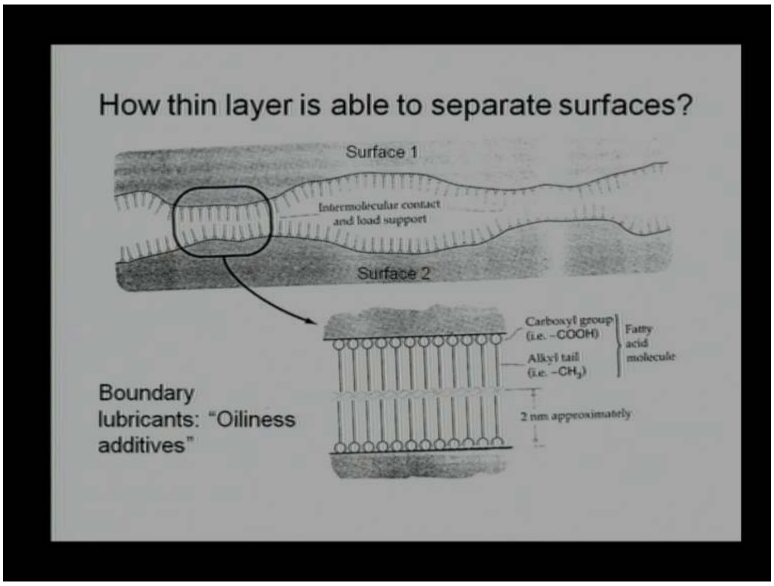

So, question is that how thin layer is able to separate surfaces? It is difficult to imagine thin layer, we are talking about lesser than 10 on 10 nanometer and we are saying that surfaces are completely separated, even though surface softness may be in micron level. To explain that this figure indicates, this is surface one, this is surface two irregular surface also been shown and it is having a some sought of carpet.

You can see the carpet this carpet has polar end and non polar end. These molecules polar end is used for a molecular attraction. So, that it makes some physical bond with the surfaces and there is a tail that provides some sort of flexibility that carpet provides they provide a smoothness of walking.

So, this carpet surface completely separates this floor surface. There are two carpets completely separating surfaces. And we talk I mean, if I take some expansion or we say that a detail view of a one of the scatch or we say that small portion, what we get from that you say these are the polar molecules, which are attaching to the surface and there is a (( ))

And overall height is 2 nanometer; it is not more than that. It is just 2 nanometer how these are made is generally made with fatty acids. Because, we said we have number of fatty acid in our body all animal fats have a fatty acids. Say that carboxyl group is here and there is Alkyl tail also (( )) like a methane.

This tail is a vertically up separating or maybe say it is not allowing other surface to come in a (( )) and this polar end is always attaching this tail to the surface. Or we say that this polar end is required as a intermediary link to connect tail with or we say connect grass with surface. Am assuming this as a grass, which grass is a something which can be easily bent and it come back to the original shape. We walk on field grass is always there on a floor and when we walk grass will bend down, when we move away it will come back to its own shape.

So, that is a grass it walks as a carpet and completely separates the surfaces that is why many times, we call this kind of attitude or this kind of a lubricants as a oiliness additives. They have oiliness property, they have attachment property. It cannot be easily separated, it requires some force some push force to separate the surface from separate the oil from the surface.

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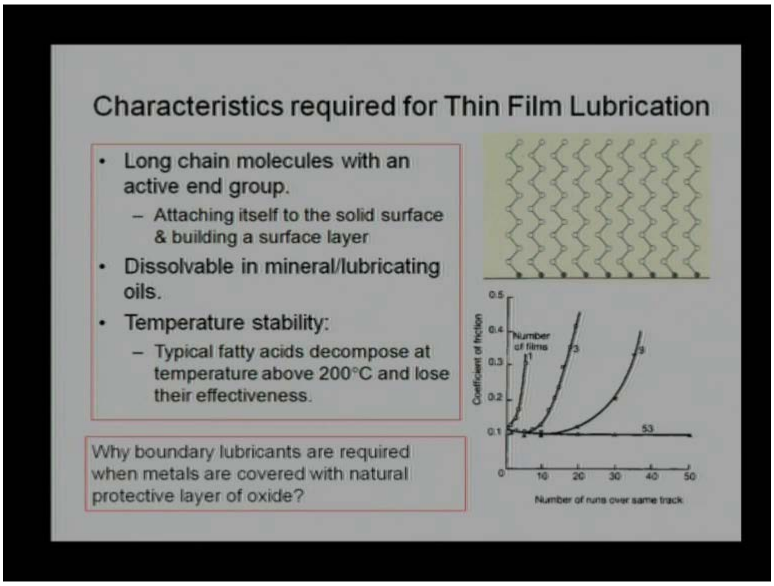

Now, we say what are characteristics, which are required from the boundary lubricants or thin film lubricants first foremost thing is that is a long chain a long tail longer the tail better the results. Lesser will be the coefficient of friction say, we require a long chain molecule with one active end group. When we are talking about the active one group this is something like a polar end polar end is always active. So, we require active group at the end of the chain, which cannot attach itself to the solid surface and bound to that surface. It does not get detached easily that is what we really require.

Now, is any additional requirement is that, it should get dissolved in minerals oils or lubricating oils if there is a lubricating oil. It should get mixed with boundary additives if it is not able to get mix properly, what will happen this kind of a polar ends or this kind of a boundary additives gets separated. We do not want, that we want complete dissolvent of the additives in lubricating oil.

And finally, another requirement comes temperature the stability. You say the temperature stability is important as temperature increases. There is a possibility of reduction in molecular attraction and that reduction will cause detachment of boundary additives from the surface that should be reduced as low as possible. We should provide lubricant in such a manner, lubricant additive in such a manner. It can with stand the temperature or operating temperature.

This figure gives explanation of the first point. We say that they are polar ends, active group ends they are connected with a surface and this is a non polar ends. This is a tail, is a chain longer the chain better the results because longer the chain it can easily bend it requires does not require a much force to bend. It is I can think about the cantilever been lesser the length of cantilever been. It will require more force to bend if longer the length of cantilever been it will require lesser force to bend.

So, that is why we want a lesser force to bend this layer within elastic climate and lesser coefficient of friction can be generate, we say produced for the surface or in this surface.

Now, when we are saying that should attach itself. We are talking about the number of layers there is a possibility of a number of parallel layers on the surface. If numbers of layers are lesser then, what will happen after the some sliding surface it will wipe out, it will be getting removed, but at the more and more layers then there is a possibility of (()) there is a possibility of that substance can be utilized.

But we are talking of this without caddied food, we are talking this kind of lubricant additive layer on the surface without any carrier fluid, which we talked over here. It should get dissolve in mineral oil or lubricating oil. If there is no mineral oil available there is no lubricating oil available over there.

And we are solely using the lubricant, which will attach to the surface. We are not using any carrier fluid in that case that this is not important. But, if we are using mineral oil or using some other lubricating oil as a carrier fluid and we are using this boundary lubricant as a additives then this kind of problem will not come.

One interesting question comes in a mind you say the why boundary lubricants are required because, we are talking about the 10 nanometer and in earlier studies. We observed or we learnt that every metal has a some sort of axial layer metal will remain virgin. It will always form some oxide layer either firmly attached to the surface or weakly attached to the surface. It can be wearied out or it can be fractured or it may be porous.

So, the question comes why do, we really require a boundary lubricants, when the metal surface are already covered with a natural protective layer of oxides. Yes, we can answer easily you say that productive layer will work for the certain load condition and then there will be transition in temperature. The transition loads after that the layer will get fractured, if you want to increase the load carrying capacity of the surface without removable layer, then in that case we require boundary additives.

Similarly, productive layer will get removed from surface and the temperature increases or temperature increases with a some sort of impact. We get fractured in that case, we required again chemical absorption layer on the surface. So, boundary additives are important, boundary lubricants are important, even though there is a productive layer of oxide, because oxide layer may be fractured with by additional load, we want to increase the load carrying capacity of the surface in that case we require boundary additives. If we are operating surfaces at the low load condition then it may not in that case, it may not require, boundary additives are not required or boundary lubrication is not required because, oxide layer itself will work as a boundary lubrication mechanism.

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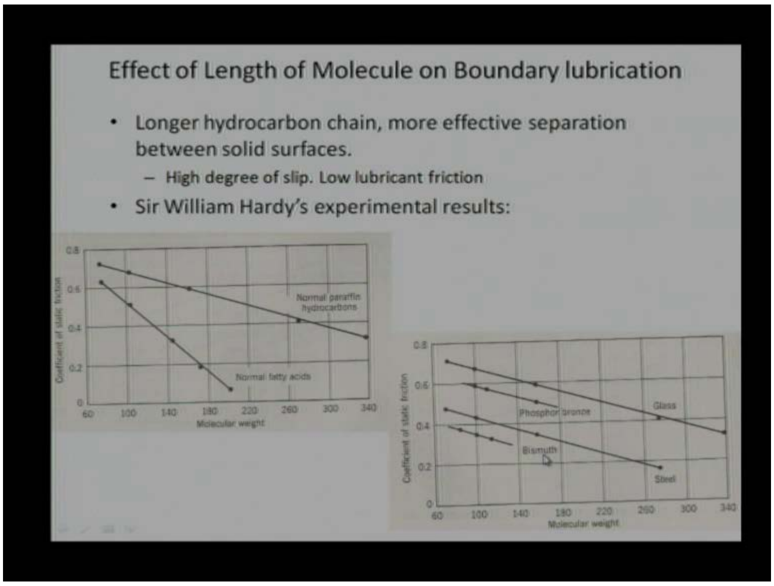

There are some results from available from Sir Hardy's experiments. He did a number of experiments with a different molecular weight, lubricant on the different length of the chain, what he says that longer hydro carbon chain more effective separation between solid surface and that will allow or bring a low coefficient of friction; these are the experimental results from Sir Hardy's experiment. We say that as a molecular weight is increasing coefficient of friction is decreasing.

It is not only for the boundary case, it may be also with a normal paraphin oil surface or normal mineral oil also. But, reduction with a boundary lubricant is much more significant. We can see that this curve has the lesser slope. This has a more slope here, for same case may be say for 180 molecular weight this coefficient of friction is roughly 0.18,0.17 ,while this coefficient of friction is roughly 0.55.

So, significantly high coefficient of friction that means, mode lubricants are always going to reduce coefficient of friction. There is another experiment we say that this kind of lubricant also depends. What kind of material is used, it is something if you use a bismith coefficient of friction will be lesser, if I use a fast porous bonds in that case additives will not give that significantly good results. They have their different chemical structure and bounding to that phosphorous bronze may not be as good as the bonding between the bismith and additives. Similarly, for the steel surface shows that, but, in all the cases we are saying the linear profile as a molecular weight increases coefficient of friction is coming down. But, attachment of individual layer depends on the material.

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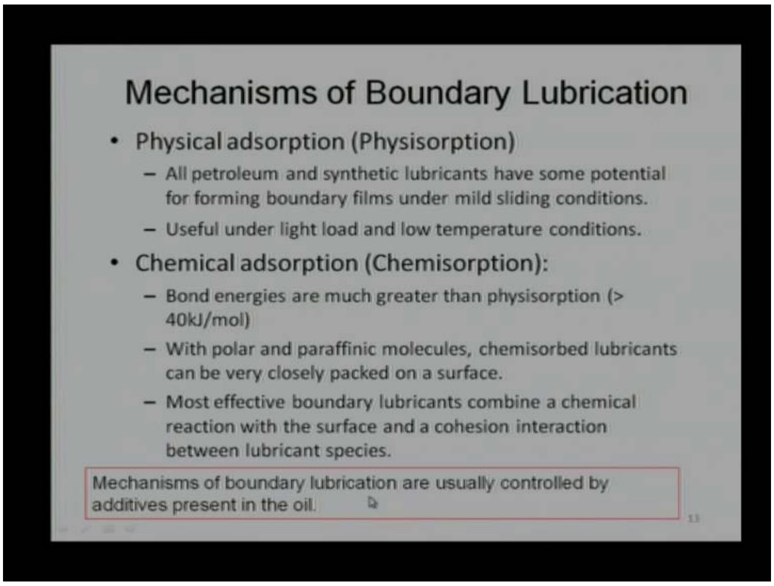

Which we are using, we can understand some mechanism of boundary lubrication say that. They are two major categories or classification 1st is the physical absorption at it happens under almost all kind of mineral oils, which have a some sort of a boundary additive. And particularly the important under the mild sliding conditions. What we are saying the mild sliding condition because, the high silding condition high shared stress will be generated and will separate the boundary additives from the surface.

So, will be this kind of situation will be good, if there is a mild conditions and load temperature condition also. If the temperature is low, then that case this will show the better performance or physical absorption will be sufficient, what we are talking of physical absorption is something like a (( )) forces and molecules are getting attached to the surface by just physical interaction. There is no change in chemical structure, there is no deformation on the surface. It is a just a share like electrostatic force connection.

While there is another category or classification, which can sustain with very high load and can see the severe operating condition also that is called a chemical absorption. We can say there may be possibility of diffusing of the lubricant in the metal surface itself. It is more like a making a firm joint and bond energy in that kind of joint is a almost a 40 kilo joule per mol it is substantially high. When you want to break this kind of joint you need to give a lot of heat or lot of tangential force to separate the layer. It is more like attaching to the surface firmly making a layer which is completely attached to the surface.

And additional thing is that in this case structure is also closely packed. Physical absorption structure may not be very closely packed few sides will be empty, where the there is no lubricant and while in the case of the chemical. One the structure is very compact size will not be free and there will be factor reduction in coefficient of friction and that is why it can see also severe operating conditions. You say that best solution will be combining physical absorption and chemical absorption together.

That will be important it will have a physical interaction as well as a chemical interaction in that case overall. We will be getting good results and almost in all lubricants which are marketed they contained above the additives together some additives related to the physical absorption some additives related to the chemical absorption.

So, the load temperature load sliding conditions physical absorption lubricant will work. Wherever, there is a high temperature high load condition this chemical absorption material will work or additives will work the only drawback in chemical absorption is they are going to corrode the surface.

See, when we study the corrosive wear that time I pointed out this mild corrosion is going to produce a protretive layer for us that should be encouraged. And lubricant experts have understood that and they made utilize this kind of concept to the corrode. The surface one way another way makes a thin layer. But, thin thickness should be such a low value it should not get too poroused and fracture toughness should be also higher side.

So, that way they are corroding the surface, but, trying to be a trying to keep the corrosion with in a control it should not be going beyond the control they should not start damaging the surface. That is why we say that, whenever we try to use a lubricant it should be studied properly. It should not happen that I know that chemical absorption is a good event, it can sustain high temperature high load you mix 5 percent you mix 10 percent, you mix 15 percent of this kind of additives. If we are keep on increasing the percentage of additives it may be much more harm full compared to not using that kind of a lubricant additive.

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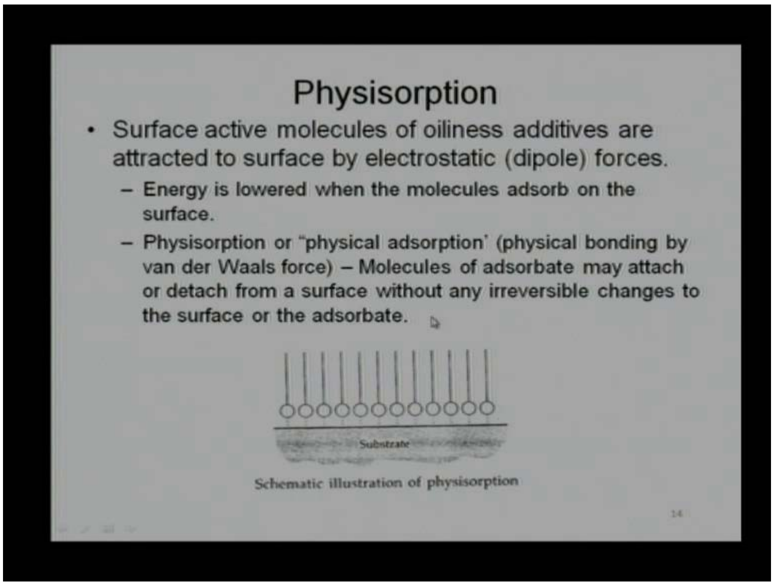

And we can say that it is this kind of a boundary lubrication mechanisms can be controlled by adding additives in oil, which I explained earlier coming back to the physical absorption. We say that these are also known as a oiliness additives. They are attached with a surface due to electro static dipole force, electro static force and that is shown over here. This is a polar end and we are showing physically they are not separated.

Just to show there is a some feel this is a electro static field there is a molecular attraction, we know electro static force is not very, very strong force. It is a relatively weak force, but, it works. It works for the mild operating conditions.

Another point is been written on the slide is that this molecules get absorbed may get attached as well as detached from the surface, without any irreversible changes. Irreversible changes is something like a will not change, will not damage the surface it can be detached it can be attached without damage to the surface. It is a dynamic process.

And if you are using a lubricant which has a tendency to absorbed that this lubricant additives that is required, if we do not use that kind of properties lubricant additives will not get mixed with the lubricant at all. So, that is why we require a property the lubricant mineral lubricant, mineral oils or any other lubricant, which we are using, should absorb this kind of lubricant additives. But in addition to that, we want these additives to get deposit in surface that is why we say that it is a dynamic process attachment and detachment will be a continuous process.

And finally, it depends on equilibrium constant and equilibrium constant will depend what kind of concentration you are providing. If you are providing high concentration more and more additives will get go and deposit on surface. If you are providing a lesser concentration then, it will lesser number of molecules will go and get the possible surface, coefficient of friction will change accordingly.

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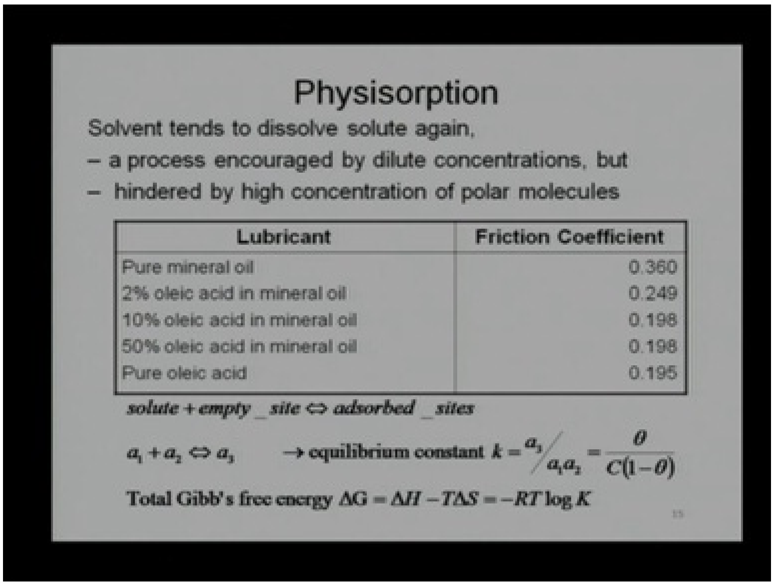

So, there is a table which shows that percentage of boundary additives. Oleic acid is one of the fatty acid and used as boundary additives. We say that, if am using carrier fluid as a mineral oil and 100 percent mineral oil coefficient of friction is coming something like a 0.36 am just taking a typical example.

When we mix two percent of oleic acid in mineral oil proper mixing it is nothing like a just mix and leave it is the proper mixing. And coefficient of friction comes down from 0.36 to 0.249 is approximately 0.25.

Now, if we keep on increasing the fatty acid percentage from 2 to 10 percent, 5 percent 5 times increase coefficient of friction will not be decreasing that substantially it is going down from 0.25 to 0.2. That is decrease is not that substantial as we are increasing the percentage. Now, if you keep on increasing from 10 to 50 percent, coefficient of friction is not changing at all.

It will remain same and 100 percent oleic acid. This is very thick difficult to pump difficult to flow it and even in that case coefficient of friction is not decreasing significantly. It is coming roughly 0.2 only.

What we are trying to convey is that effective percentage should be utilized, it should not that we keep on increasing the percentage. I talk early for the chemical absorption that will be harmful. Even for the physical absorption because, oleic acid is a costlier compared to mineral oil, if I keep on adding this kind of additives overall cost of the lubricant will increase, which is not a desired by number of customers.

Now, what it says in addition to this, this kind of process is removal and attachment with the surface. Generally encourage by the dilute concentration. The concentration is a low than there will be frequent engagement and disengagement of the lubricant additives from with a surface.

However, if the concentration is increasing there is a lesser possibility of getting detached from the surface and often, we give this kind of equation. We say that solid mineral oil plus lubricant additives, we are assuming it has a some sort of a 1 (( )), a 1 molecules and empty side. Whatever the surface has empty sides which can be occupied by lubricant additives is something like a 2.

Finally, only the absorbed sides are equal to a 3, which are really absorbed, it is nothing like a every side will be occupied and equilibrium constant somewhere, k comes somewhere, like a depends on the percentage. How much percentage we are sorry depends on the absorbed side. If we are increasing the concentration then theta will also increase.

So, the equilibrium constant will change that can be used in a Gibbs free energy Gibbs free energy, we can say it is more like a potential energy, of a surface, of a material. That much energy is required to disturb the surface to move the surface or to change its position.

So, Gibbs energy gives what is a, how much energy we require to change the position and it shows clearly it depends on the temperature. If the temperature is increasing this term will increase in magnitude and is a subtraction. That means, Gibbs energy will change, Gibbs energy will reduce, that means, we require a lesser energy to disturb the equilibrium.

Otherwise, if the temperature is reducing we require more energy to disturb the equilibrium. In other words, temperature is bad option for the physical absorption, if temperature is increasing, we need to see physical absorption will not be effective either we should increase the concentration or we should change from physical absorption to the chemical absorption.

We will continue this topic in next lecture, lecture 12. Physical absorption will be continued and will come back, come to the chemical absorption with this am ending this lecture. Thanks for your attention.