Tribology

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Lecture. # 18

Lubricant Additives

Welcome to 18th lecture of video course on tribology. This is our last lecture of module four. We have covered three modules earlier that was introduction to tribology and friction; third module was on wear, and fourth module on lubrication. And this is a last lecture in lubrication module, the topic of present lecture is a lubricant additives. It was mentioned earlier, it is very difficult to get the performance by single lubricant, without any addition to that. We require number of properties and single oil can sustain or provide those kinds of properties, that is why we require lubricant additives.

In the last lecture, we covered EP additives and friction modifies those were additives mixed with a mineral oil to enhance the property related to friction, and load carrying capacity. Today we are going to cover few more, but before I start up that there is a need to spare some time finding what is the need of these additives with some examples.

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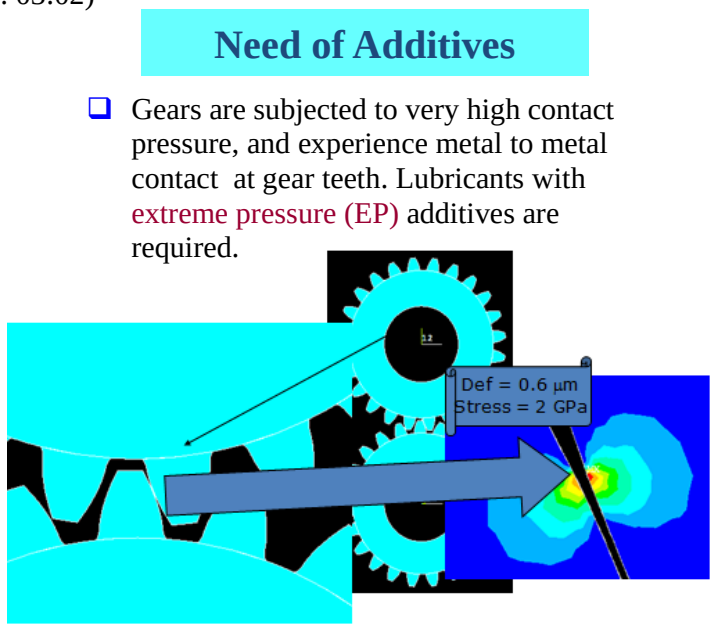
Need of Additives

- Gears are subjected to very high contact pressure, and experience metal to metal contact at gear teeth. Lubricants with extreme pressure (EP) additives are required.

First example is gears, say the gears are subjected to very high contact stresses, and due to the high contact stresses lubricant will be squeezed out. There will be metal to metal contact. To avoid the failure, to avoid the seizure of gear, we require EP additives. What we call as an extreme pressure additives. As in earlier lecture was mentioned is a misnomer even though the name says the extreme pressure additives, they work with the temperature; they are effective at the high temperature, and because of the high temperature seizure occurs,

welding of two component occurs. And we want to avoid that means EP additives are effective at the high temperature additives or the high temperature.

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As, I mentioned that typical example is a gear: this is simple solid model of the gear pair and there is a contact shown over here the whole gear load is transmitted on either on one tooth pair or two teeth pair or three depends on the contact ratio. Let us take an example of the one tooth pair: if the one tooth or one gear or gear and one tooth of pin are in contact.

If I magnify this I can see the contact over here this is very small patch, the whole power is transmitted at the dispatch naturally contact stresses will be phenomenon and interesting thing is that all other gear teeth they remain ineffective that time is the only one or two depends on the sliding ratio or contact ratio. Now, if I further magnify stress pattern at this patch I am able to see this is stress pattern the right portion shows a stress equal to the 2 giga Pascal; 2 giga paschal is very, very high stress steel strength and the compression may be around 500 mega Pascal 600 mega Pascal without heat treatment then in these kind of the gears require a good heat treatment to improve their compressive strength.

And that is why I say that improving strength is one point, but at high contact very high pressure wear will be the phenomenon if we do not use EP additives wears in terms of seizure. We say that complete binding of gear pair; will not be able to separate. To avoid that kind of thing we require EP additives.

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Need of Additives

- I.C. Engine parts are subjected to high temperatures. Lubricants need to be oxidation resistant.
  - Detergent and dispersant additives to remove combustion and breakdown products of the oil from the surfaces
  - Corrosion inhibitors to prevent corrosion caused by combustion and oxidation products
  - Seasonal lubricants ~ different climatic temperature.
- Refrigeration system lubricants encounter the low temperatures (below 0 ^{o}C), the oils need to have low pour points.

Let us take another example see IC engine typical troposphere, which sustain which bears all kind of conditions and major thing is a high temperature. We know operating temperature most of the components are more than 100 degrees centigrade even the cooling water is used, but the operating temperature will be 100 degree plus because, we do not want to lose efficiency. In that case, all the liquid lubricant need to be resistant to the oxidation, how oxidation will happen and due to oxidation, there will be some sort of deposits on the metal surface that will further hinder the functionality of dispersant. That is why we use detergents and dispersants to avoid hard deposit to be fixed or made on the surface.

Similarly, because of the high temperature there is more possibility of acid formation from the liquid, which will corrode this component that means; we need to use corrosion inhibitors also. As in previous lecture, we discussed about the multi grade oil say engine works with a different temperature at the start temperature may be 20 degree, may be 30 degree, may be 40 degree, may be 50 degree depending on the environment and reaches to the temperature more than 100 degree centigrade. So, it requires variation in performance based on operating temperature and that is possible by multi grade oil that is why we require additives. And in previous lecture, we mentioned that, we use polymers, we add polymers. Those are polymer additives will be known in class of the additives.

The third example is a refrigeration system; we know the refrigeration system need to operate at a very low temperature that is the meaning of the refrigeration. And

Lubricating oil required a flow ability to get circulated from one place to other place so that it can carry wear Debby particle. For that purpose, we require low temperature lubricant as I mentioned that we require number of properties from a lubricant. In this situation we need to add additives to impart low temperature properties as well. So, this is indicating there is really a good need of additives and in commercial oil available in the market we do not find any oil without any additives. There will be some additive one form or the other.

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Importance of Lubricant Additives

Surf 1	Surf 2	Lubricant	k_1
52100 steel	52100 steel	None	1.0×10^{-3}
52100 steel	52100 steel	Paraffinic oil	3.2×10^{-7}
52100 steel	52100 steel	Paraffinic oil + additive	3.3×10^{-8}
52100 steel	52100 steel	Engine oil	2.0×10^{-10}

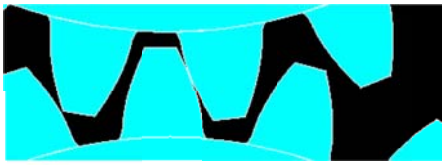
For engine case, this slide shows some sort of experimental results, say that when the engine bearings assuming the stainless steel; assuming the cramming steel surface one and cramming steel surface too. We do not use any lubricant then we find wear constant also probability of formation of wear particle is roughly 10 is to minus 3.Using paraffinic oil, which is good oil; good lubricating oil this probability decreases it reaches somewhere 10 is to minus 7 then this there is a benefit of 10 thousand times wear will decrease roughly 10 thousand divide by 3 with 3 thousand times. Now, if we use a paraffinic oil with temperature additives, temperature resist additives, corrosion inhibitors then wear rate will further come down that shows a 10 times benefit compared to simple paraffinic oil.

We use a complete package with the anti-wear additives, EP additives, all additives, anti-forming additives everything is mixed, and that is what we know as engine oil; that is a complete package. That wear rate decreases significantly even the benefit compared to that observation is are almost hundred times that means, if you want very low wear rate we should use additives, but without understanding we cannot go ahead. I, it is the conflict to each other there is always a interference of one additives with other additives you think over we use a

soapy layer to avoid the deposits, but the soapy layer itself make corrode the surface. So, there is always some sort of contradiction and to avoid that kind of contradiction we need to understand what those additives are? And how they function?

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Desired properties of lubricants



- **Adequate film strength**
- **Chemical stability**
- **Adequate lubricity (Adhesiveness to surfaces)**
- **Purity (freedom from contaminants)**
- **Non-corrosive**
- **Good sealing properties**
- **High VI (change in viscosity with temperature)**
- **Minimum volatility or out-gassing**

In brief about the additives we can say we require a number of properties from the lubricant that is why we require additives, we require adequate firm a strength from a lubricant example was given over both the gear pair; where the contact pressure is more than 2 giga Pascal that means, a firm strength need to be that that much level. Further they require chemical stability liquid lubricants or many times in the acidic nature. They will corrode the surface so in that case we require chemical stability of those lubricants as well as a non-corrosive nature of these lubricants. To give a firm strength, adequate strength can be termed in EP additives time or in boundary additives way.

Further we need to be free from a contamination, it should not happen the liquid lubricant is coming with some sort of contamination from environment and gaining more and more wear or developing more wear. In addition, if there is a possibility they have some sort of sealing properties, which is very difficult to think, but it is required otherwise you will be requiring additional seals; additional components. They need to have a high VI, they should not change viscosity that a temperature is to significant level enough it is inherent in liquid lubricant to decrease viscosity with increase in the temperature, but the rate of decrease should be controlled; rate of decrease should be low.

Finally, comes out gazing it should not happen that liquid lubricants are not to be vapor and evaporate. Sometimes we are keeping one litre of oil and after some time we find out it is only the half of the oil is remaining and half oil is evaporated, but is not desirable and we should use additives to avoid that.

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Lubricant Additives

- **Elements incorporated into either a liquid base (mineral oil, synthetic fluid, etc.) or grease.**
  - **Need to be soluble or uniformly dispersed throughout the carrier media.**

ACTION	ELEMENT
Detergent or dispersant additive	Barium (Ba), Calcium (Ca) , Magnesium (Mg) , Sodium (Na)
Extreme-pressure additive	Boron (B)
Anti-wear additive	Copper (Cu), Lead (Pb) , Phosphorus (P) , Zinc (Zn)
Friction modifier	Molybdenum (Mo)
Anti-foaming additive	Silicon (Si)
Anti-oxidant additive	Zinc (Zn)

Sometimes we use a metal as liquid lubricant additives also or they form some sort of chemicals with acid, esters or some other basics. So, what we say that liquid lubricant; Liquid lubricant can be defined as elements which incorporated either in the liquid base or grease, so we are not avoiding the grease we are saying that liquid this lubricant additives also come in grease. And Liquid lubricant not only the mineral oil it can be added in synthetic oils also, but what is the requirement they need to be soluble properly, mixed, it should not happen that they are floating and uniformly dispersed. If it is not uniform distribution then few metal parts will get a good lubricant and few metal parts will not get.

So we require a uniform distribution. Some metals metal elements or we say that some material elements which have been used as additives are listed on the right hand side of this table and their function, their action is mentioned on the left hand side. I use the word earlier that detergents or dispersants additives. We know them soap are generally made with the elements the calcium is the common element; sodium is the common element, which is used to make the soap. Similar elements can be used to make a detergents and dispersants. How detergents dispersants acts will be covering in the few slides in the next few slides.

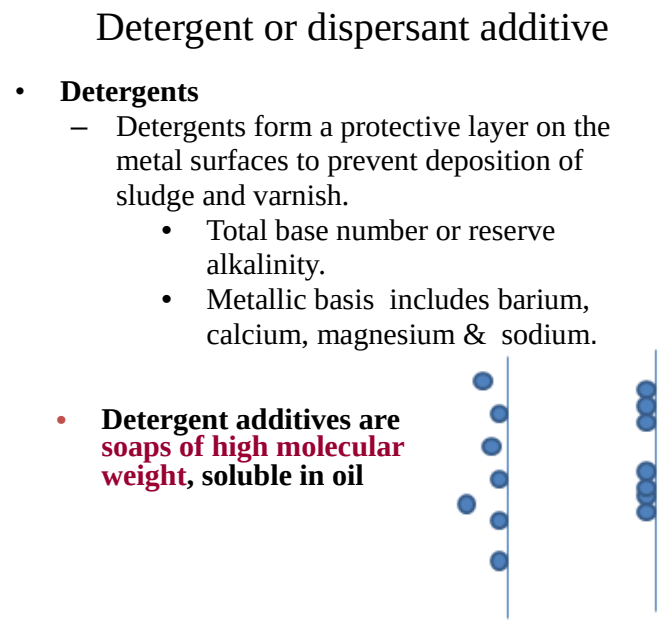
Similarly, we have discussed about extreme pressure additives we talk about the chloride, sulphur and phosphate, but they require some sort of elements to get so that the layer can be made one of the common EP additives is boron. Coming to the anti-wear, we have number of options available say lead zinc, zinc is one of the very common anti wear additives copper, phosphorus. Now, there is a slight change we say that EP additives and anti-wear additives they work by a large similar manner.

And EP additives also provide strength to the surface; reduce a wear by reducing the seizure capabilities or capacity of the metal pair. Anti-wear also is a same thing it avoids a wear, it coats a thin layer on the surface, so functionality point of view both have same function, but operating temperature is different. The EP additives the operating temperature at the junctions at the interfaces higher than anti wear additives, that is why; initially the anti-wear came in a after that when we provided or additive provide extra strength that what treated or where the those additives were named as extreme pressure additives.

In my last Lecture also, we covered a friction modifiers. You say all sort of solid lubricant act as a friction modifier. They require some sort of carrier fluid, so that these particles or the particles of solid lubricant can be transferred from one place to the desirable place. this is a friction modifier and here example is given molybdenum disulphide, it can be silver also it can be graphite; it can be PTFE; we have huge number of additives in this category then they are two interesting additives what we call anti foaming additives we use a dispersant and detergent for their functionality, but these additives create anti foaming problem they make bubbles and we know very well the bubbles if there is a bubble then flow rate will come down that will hinder the flow rate or reduce the cooling capabilities of that liquid.

So we require anti foaming additives and the element is used in this silicon. Similarly, we have anti-oxidant additives, which reduce the chemical reactivity with oxygen and increase the life or service life of the lubricant. zinc is one of the most commonly used that is why; we say that zinc base additives can be used as a anti wear additive and can be used as the anti-oxidizing additives. It can work with dual purpose it can fulfil dual purpose.

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Let us start from first category, what we say that detergent or dispersant additive. There are different theories different hypothesis, how detergents works. What we feel that detergent forms a productive layer on the metal surface. To prevent deposition of the sludge and varnish, which comes from burning of lubricant and getting after, getting oxidation so, those should be avoided. That is the one function, but there is other possibility that additives that this kind of additives can wrap around particles and avoid the increase in the size or growth of this particle. Often presence of detergent is measured with TBN number, what we call as a total base number. We have a two number; we quantify detergents or add these with the two numbers TBN and 10 if the acid number is increasing that means base number is decreasing.

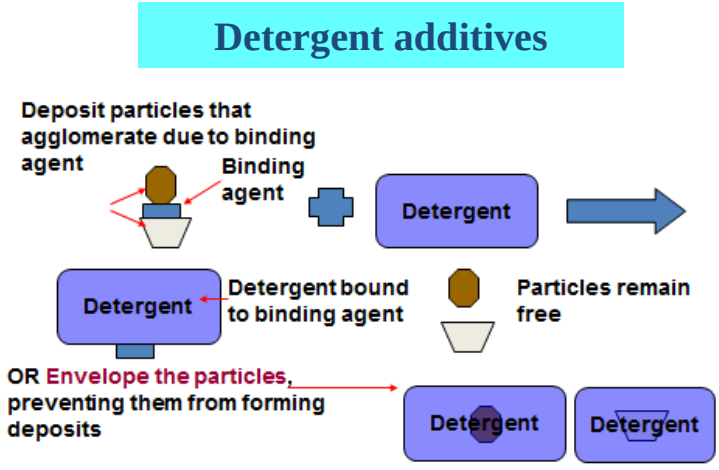
And that is why we say, that we should check these numbers. We want to find out whether there is a sufficient detergent or not if there was internal function of detergent and these are some elements link given which help in detergent. Now, what we are discussing with or we say the, what is the functionality of detergent. I am assuming that there are some wear debris there are some sort of sludge particles; some sort of non-desirable particles coming near the surface so, I am assuming this line is representing any metal surface. I am keeping in a

vertical direction and these are the particles may be in a nanometer size or may be in micron size they try to come and get deposited on the surface they have some sort of gummy characteristics.

They have some sort of adhesiveness; they will come and stick to the surface, but they do not have good properties; they will be having wear properties also that can scratch at the surface. So what is required, we require avoiding this kind of accumulation of this particle. If we are able to avoid this kind of accumulation, this kind of additives can be removed easily by filtration system or even if they are not removed they remain in suspension. They are not going to harm the surface; service life of the, troposphere will be much larger. So, this is the main function, do not allow accumulation on the surface and let the surface to be free from this particle as far as possible.

This is possible with some sort of soapy characteristics say that detergents or detergent additives they are soaps of high molecular weight which can stick more easily to the surface; if the molecular weight is low can be removed easily. High molecular weight they stick too much or we say that a greater force and they need to be soluble in oil or happen that they get separated from the oil.

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This slide shows the some sort of hypothesis, not 100 percent correct, but some sort of hypothesis how detergent will act. We say that detergent acts because of the binding particle they get accumulated, agglomerate on the surface, because of the binding agent. Now, have two approaches, either in capsulate this particle or in capsulate binding agent. So that, they do not stick to the surface. I can take simple analogy from police and crime action so criminals

are generally kept in cell away from the society? Which should not harm the society is nothing there is no purpose that you take those criminals and they kill them or beat them in prison. What we are doing in this case as same thing we try to keep a cage around ,this particle they do not agglomerate they do not spoil the metal surface. They are trying to keep it out away from the desirable surface.

The same thing: we are assuming there is a detergent and then detergent tries to avoid encapsulate binding agent and let particle will be free. A particle is free it cannot have will not have a binding agent; it will not increase in a size that is the one point. There is other option encapsulate this particle and let binding agent be free. So, either of this approach will work. It will solve the purpose for which we require detergents and this analogy works with almost for every additives. We have a number of examples we will explore those.

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Detergent or dispersant additive

- **Dispersants**
  - Suspend harmful products (i.e. dirt, water, fuel, process material, and lube degradation products such as sludge, varnish, oxidation products) within the lubricant.
    - Dispersants isolate the particles from each.
  - A large hydrocarbon tail and a “polar group” head. Tail section serves as a solubilizer in the base oil, while polar (functional) group attracts particulate contaminants in the lubricant.

Detergents, like dispersants, are blended into lubricants to remove and neutralize harmful products. In addition, detergents form a protective layer on the metal surfaces.

Same action with dispersants, only the difference comes that is indicated here. So, that detergent like dispersants are blended in lubricant they are mixed with a lubricant, to remove and utilize harmful product; remove from a surface and utilize. But in addition detergents have additional functionality to form a protective layer on the surface while dispersants they do not have that functionality, they do not require that functionality to make a protective layer on the surface. So, in this situation dispersants with anti-wear additives can be utilized easily, because they do not make any layer, but they try to suspect particles; it may be that particle

may be undesirable water; undesirable fuel or some sort of process fluid or oxidized product or bunch product that to be within liquid lubricant.

So, we can say dispersant isolate the particles from each other, they make a barrier between particles and they do not allow particles to join together. The way we have understood the boundary additives since they have also similar kind of characteristics they have a polar head and the long tail. Long tail is required to get suspended in liquid and polar head is required to get attached to that particle. Now, depends on which particle we want to encapsulate; which particle we want to really capture, additives will change accordingly, but they will be in the same category of dispersants. That is we can say they have almost same functionality as a detergent has, but detergent will have additional property, additional requirement compared to dispersants.

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Anti-wear additive

- Prevent metal to metal contact
  - Lighter to moderate loads (bearings).
- Chemical active — Coat a protective layer on the metal surface by chemical decomposition and absorption.
  - Molybdenum disulfide and graphite additives are a special form of anti-wear additives known as anti-seize agents. ~~ Depletion.
  - Zinc compounds
  - Stearic acid.

We have anti wear additive, say that anti wear additives may work like a boundary film between the metal pair. It prevents metal to metal contact by making thin layer, thin coating on the surface. See, it has both a function to reduce friction and as well as reduce wear; reduce friction because they make inter phase weaker and allow lesser friction or lesser top to the exited on the surface. But to differentiate from the EP additives we are mentioning this kind of a surface is for lighted to moderate load. If there is a load is extreme load, very high contact pressure then we are bound to use extreme pressure additives, which have more bond energy compared to anti wear additives.

And couple of examples are given, we have already discussed about the stearic acid which is a boundary additives is the polar lubricant additives, it has a polar had to get attached to the surface I mean to tell the way we mention about the dispersants they have almost the similar

kind of physical form. Zinc compounds ZDDP is one of the common component used or common additives used as anti-wear additive even the molybdenum disulphide, then graphite can work as a anti wear additive. Because they really reduce interfacial strength they reduce the friction so they can be named; they can be put in a category of anti-wear additive.

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Anti-foaming agents (Foam Inhibitors)

- Formation of air bubbles in the lubricant.
  - Lubricant foams due to agitation and aeration that occurs during operation.
  - Detergent and dispersant additives tends to promote foam formation.
  - Interfere with flow rate and heat transfer.
  - Foaming increases oxidation.
- The additives lower the surface tension between the air and liquid to the point where bubbles collapse



- Usually long chain silicon polymers are used in small quantities of about 0.05% to 0.5% by weight. polymethacrylates

Next category is an anti-foaming additive. This picture shows a foaming action of a liquid lubricant. It often happens in the bearings when we are pressurizing the liquid to pass through the convergent region inclined surface as a liquid is a pressurized and passed.

When released, it comes with the some sort of bubbles because of the surface tension and they remain in bubble form so easiest way is that reduce a surface tension collect this bubble as soon as possible, because if there are so many bubbles the pump ability will reduce. We required an extra force to pump the liquid. In addition these bubbles may keep some sort of air or oxygen with that in contact with the surface.

So they will increase corrosion probabilities or rusting probabilities with that and we want to avoid it. We say that anti foaming or we say the foaming can be deforming as a formation of an air bubble in the liquid and we were talking about the air coming with the contact with the liquid or coming in a contact with the solid surface. Sometime due to shaking and all this

kind of foam will be made and if we are using detergent and dispersant additives foaming will be slightly on higher side that will increase the tendency of foam or making bubbles in liquid. As, I mentioned it interferes with flow rate.

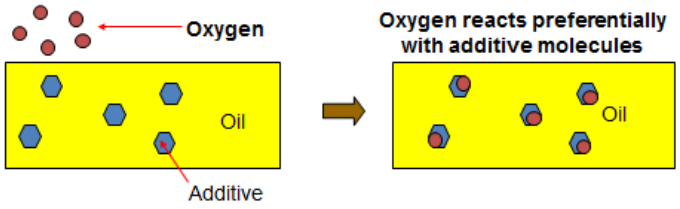
In addition, they interfere with the heat transfer also because the air has a low heat transfer rate and liquid has a high heat transfer rate, but if we are providing some sort of bubbles in between or some sort of bubbles are coming in between overall heat transfer rate will be reduced because of this. In addition this foaming is undesirable from oxidation point of view as it provides an air or oxygen to surface. Now, we need additives which reduce a surface tension between air and liquid to collapse a bubble and one of the common additives is based on the silicon.

The silicon polymers are used in very small quantity in liquid lubricants, to avoid the foaming; to avoid the fact on heat transfer and mass flow rate; to reduce the possibility of oxidation as a collapse of the bubbles before reaching to the contacting surface. We will reduce an oxygen or air which is carried over the surface.

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Anti-oxidant additive (Oxidation

- Oxidation due to high temp. And pressure. Products of oxidation.
  - Gummy. Deposits on surface. Corrode cadmium, copper & lead alloys.
  - Power loss due to increased viscous drag & difficulties in pumping.
  - Replace oil if TAN > 3



Now, as I mentioned about cage around the undesirable surface undesirable particles. Same thing, we can explain action of anti-oxidant additives or sometime we use a word oxidation inhibitors, they encapsulate oxygen itself so that oxidation happens at the high temperature in a high pressure. And if the oxidation happens what is the loss? Some sort of gummy deposits will be met on the surface reduce a clearance, change physics, change the mechanism and cause undesirable functions or undesirable failures of those tribo spheres. And when this kind

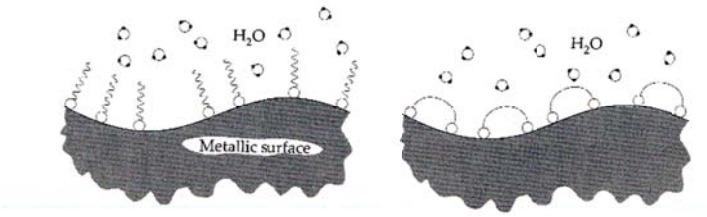
of gummy substance happen they are very sensitive towards the couple of materials like copper and lead alloy, which are very common bearing materials that means, if we are using oil for engine we need to use anti-oxidant otherwise all the bearing will get corroded.

Similarly, as is mentioned that it reduces the clearance and addition what we say because of this gummy substance viscosity of the liquid will increase. Viscosity of the liquid will increase that will cause more and more friction loss, more power loss. However, they function we are trying to keep a same in we have some sort of additives allowing whenever they find an oxygen nearby their chemical affinity is more than the liquid lubricant. They immediately come around oxygen with the surface and consume that available oxygen, but as these are chemically acting with the oxygen, the depletion is obvious after certain duration. Anti-oxidant need to be added again in oil or that is why as a reconditioning of oil, we need to change the lubricating oil by adding some sort of additives in liquid lubricant either directly. We cannot do directly, so that is why we require some sort of refining process.

And often, that is quantified when this oil need to be replaced by 10 numbers is one of very common parameter, whenever we check lubricant oil will be discussing this in oil conditioner monitoring. When we want to find the health of oil we go ahead with oil conditioning monitoring, we try to find out the parameters whether element have depleted or desirable properties have depleted and that one check is a 10 number, that 10 number more than 3 that means it does not have anti-oxidant additives. It is ready to oxidize, is going to increase the viscosity of oil, the better we replace it with new oil or you need to recondition that oil.

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- **Corrosion inhibitors**: Used for non-ferrous metals (copper, aluminum, tin, cadmium, etc. used in bearings, seals). Protect surfaces against any corrosive agents (sulphur, phosphorus, chlorine, and oxidation products) present in oil.
- **Rust inhibitors**: Needed for ferrous metals. Oxygen dissolved in oil & water. Polar type adsorbed strongly upon metal surface. Neutralize acids. Sulphonate, phenate, Amines. ~~ Depletion

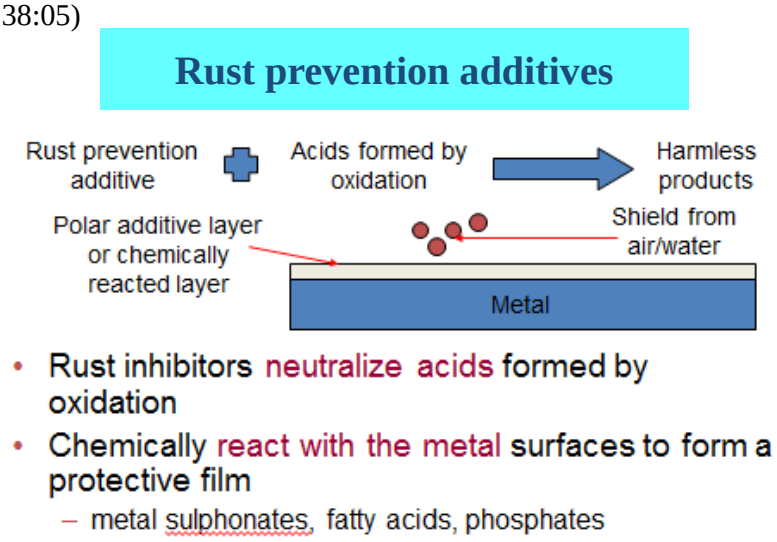


There are some other additives, what we keep in a same category that is known as a corrosion inhibitors and rust inhibitors. We are keeping in a same category reason being, that rust is the name given to a ferrous metal, if the ferrous metal gets corroded we will say that is rusty. It is only the English language change chemical form will not be different. When corrosion it is a corroding the surface is making some sort of porous layer on the surface and that is easily removed; that can be easily removed that will cause a wear rate on the surface. Keep in a mind, we use anti wear additives also as a corrosive agent or we say mix or corrosive layer on the surface, but the thickness of that corrosive layer is much smaller.

Earlier case the corrosive layer was smaller while in this case corrosive layer thickness is more. Thin layer has as almost same strength, but thicker layer will have lesser strength that can be removed easily. Now, we say that this can be avoided by removing oxygen, which is dissolved in water or oil wherever metal surfaces are used, and it again and again getting consumed so, we need to replenish it. The depletion is possible we need to recondition. Again, how they are working, we can see there are two different forms which are shown as a polar head and this long chain.

We say that it comes in a surface contact, it gets attached on the surface and does not allow oxygen or water molecule to come near the surface. Keep separation from oxygen and water molecule, also that is one-way physical point and chemically, they make some other form which is not harmful.

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Now, again one hypothesis is that, this kind of additives are making thin layer and providing shield against oxygen and water. That means; every solid lubricant should work as a rust inhibitors. It comes in contact and attach to the surface reduce the chances of rusting; reduce the chances of corrosion. If we are using anti wear additives that also are rust inhibitors; that is the contradiction we are saying anti wear additives is a chemical form they make corrosive layer on the surface, to prevent the corrosion. So, they can be used. We can use the word for rust in anti-wear additive as rust inhibitors. They allow corrosion for smaller scale only for final level only, which is negligible. There are some example given in a phosphate we have already covered it makes a layer on the surface , low friction surface and avoid further rusting of the surface.

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Pour point depressants

- Lowest temperature at which the lubricant will flow.
  - Forms waxy crystals at lower temperatures.
  - Encapsulate crystal so that it cannot grow.
  - OR change the structure of crystals making them amorphous (crystals of different shapes and sizes)
  - Pour point depressants reduce the pour point and are therefore required when operating at lower temperatures.
  - Methacrylate polymers, polyalkylphenol esters

A kind of additives or poor point depressant, we say that a refrigeration system, we require operating temperature much lower the 0 degree centigrade with the most of the liquid lubricant will not be able to flow easily, unless they are mixed with the some sort of additives. So, we can say while lowest temperature at which lubricant will flow. In absence of additives they form some sort of crystals is a waxy crystals they increase the viscosity drastically or there is drastic increase in the viscosity because of the waxy characteristics. They will not flow easily and will not reach to the desirable place.

So, if you want to avoid that kind of crystal formation, we should not allow one crystal to come in a contact with the other crystal is something like divide and rule. It divides all the crystal particle they remove one from other, do not allow agglomeration of this waxy

particles or waxy crystals. Right, so what we say that we try to avoid the waxy formation or it changes some sort of structure of this lubricant so that they do not thicken too much with decrease in viscosity, decrease in temperature. We say that this kind of poor point depressants, they reduce the poor point and can walk with low temperature. Methacrylate polymers are one of the common poor point depressants. We have covered few additives, but as I mentioned that gaining the knowledge will always be helpful as we have understood that solid lubricant may act as a rust inhibitor, corrosion inhibitors. That means; when we are doing coating of solid lubricant on the surfaces, then we do not really require additional rust inhibitors, if we know that kind of solid lubricant will remain there for long service life.

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Interference between additives

- Detergents & rust inhibitors can significantly suppress lubricating action of ZDDP.
- Corrosion inhibitors contaminated with ammonia lead to extensive plant damage
- Dispersants accelerate the oxidation of oil & anti-oxidants must be included when these additives are used.

But if there are some detergent and rust inhibitors, then we need to be very careful about physical attachment or chemical attachment of additive through surface. Because detergent and rust inhibitors, they will try to separate anti wear additives from the surface that means; we require a perfect combination or perfect percentage of detergent and rust inhibitors with anti-wear additives or ZDDP.I am keeping 3 percent of ZDDP, which has high concentration. We know higher the concentration more possibility of attachment with the surface and low percentage of the detergent, but that low percentage should not be very low, which avoids this functionality.

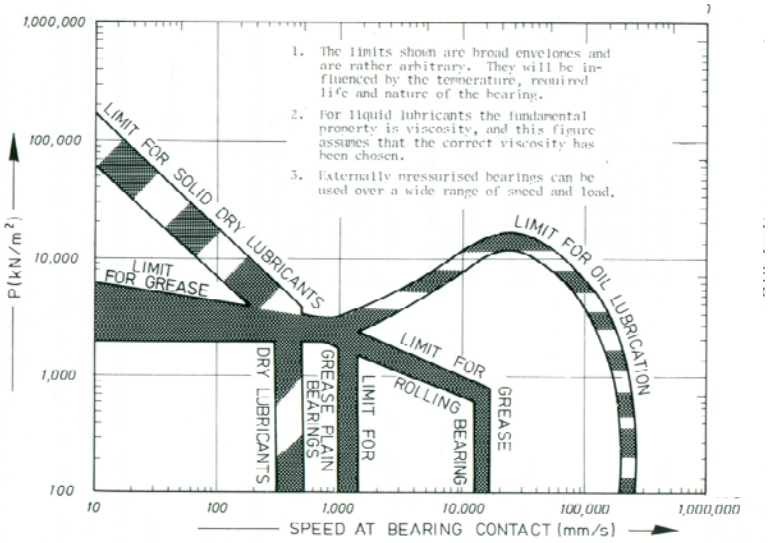
So, a good permutation combination is required; good number of experiments is required as a really very hard research area. People have done a lot of research, but they are keeping all in close book they do not share easily. And that is why the most of the industry they do not document or they do not publish results. They publish the results only metal layer or element is doing this or a complete package is working satisfactorily, but they do not share all the

results. Now, there are some precautions which we need to be accounted we say that corrosion inhibitors if we use when ammonia plant, where there is a possibility of ammonia leakage then there is a possibility of damage.

So, try to avoid corrosion inhibitors in presence of ammonia, which has possibility to damage the overall system. Then we are saying, wherever there are dispersants available or used we should use anti-oxidant along with that because, we know dispersants will allow more and more oxygen or more and more air to bring any other surface they will collapse the bubble or they will make such a manner encapsulate the surface, remove the coating from surface, allow free surface to getting exposed to oxygen so we should use anti oxidation for that purpose.

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Lubricant Selection



Now this is a last lecture, so I am giving a few slides on a lubricant selection. This slide is taken from one of the hand book, which shows some limits for the grease solid lubricant and liquid lubricants, but these are not very strict limits; that is why you can see the bend from one lubricant to other lubricant, there is some sort of variation possible or we say that lower speed. In this case the speed, on x axis is given in mm per second, while pressure on y axis is given in kilo Newton per meter square or kilo Pascal. Now, for the solid lubricants, for dry lubricants speed and the pressure limits are lower. You can see this kind of rectangle, it is

lower and this is a transition some sort of a liquid some dry lubricant also can act in this way this is a minimum limit as this is a variation.

Now, there is a limit for the grease when the grease is been used for plane bearing or employed for the plane bearings. But the limit for the rolling element bearing or the grease limit for the rolling element bearing is in a higher side that is interesting to note. If, I use similar grease is a lower limit for the thin bearings, but higher limit for the rolling element bearings what is the reason say that in a plane bearing there is more sliding, more friction, more heat generation for the same heat speed because of the high coefficient of friction. While in the rolling bearing coefficient of friction will be lesser so more speed can be allowed for this purpose.

Coming to the liquid lubrication, it has higher speed limit, but lower limit compared to solid lubricant particularly for the pressure side. Highest limit is for the solid lubricant, which can sustain more pressure as I mentioned these data are taken from the hand book; Hand book is around thirty year old so this gives guidance, but not a firm limit. we can see, yeah if there is a limit for the dry lubricant I can try grease; that there is a limit for their grease I can try for the liquid lubricant; if there is a limit for the liquid lubricant we can try gases; if the speed of operation is increasing, while if the pressure is increasing we will shift from liquid lubricant to grease to dry, to the solid lubricants.

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Lubricant Selection

- Choosing lubricant only to meet the friction and wear requirements.
  - To solve the cooling, contamination and corrosion problems.
- First step toward selection:
  - Lowest initial cost without any facility for re-lubrication. Ex: watches, clocks, door locks, sewing machines, etc.
- Second step: Is there any need to change lubrication system due to excessive load and/or speed, heat or debris? If yes refer Table:

Some important points have been given on this slide, starting from scratch - chooses lubricant which only meet the friction and wear requirement. That is the first point for tribological application. However, if a design says now these liquid lubricants are also required for cooling, then lubricant selection will change. And there is too much contamination we require

to carry this liquid lubricant. This kind of contamination do not allow to get accumulated on one surface that liquid then tries to be different or if there is a possibility to avoid the corrosion. Take an example of number of metal parts - steel parts when they are finished, when they are fabricated.

Let us take an example of lathe machine, when we fabricate a shaft on the lathe machine give a finish to the surface. Immediately, you can say the labor or person, who is involved in fabrication he will apply a grease layer so that corrosion can be avoided. So we say, that if lubricant is required to avoid corrosion, the choice will be different, liquid is required for cooling choice will be different; liquid is required for contamination to avoid the contamination that choice will be different ,but we are concentrating more on the friction and wear requirement these are the prime requirement.

There is a possibility of additional requirement. There is a possibility of temperature going high and we need to keep lower temperature then the cooling can be added aspect that may be quiet possible. We can use same lubricant, but with a pressurized liquid to allow more and more cooling. So, keeping in mind we are worrying we are thinking only from friction and wear point of view and then we are suggesting how to select lubricant.

Say, first step think about the cost. It should be lowest cost for commercial application. Lowest cost needs to be there or otherwise we will not be able to justify our selection. If possible think about the no lubrication or no relubricate system, once we applied and then think we do not have to re lubricant it again and again. We are away from this kind of worry. Typical example for this kind of application is watches. We know that if the lubricant costs very high then will not be able to use in watches, clocks, door locks, one of the cheap components in washing machine. We do not require relubrication frequently in washing machine. Other than washing machine, in all door lock we do not do unless some sorts of corrosion happens because of the environment.

So, think about the cost; think about the relubrication; if try to avoid the relubrication, try to keep minimum cost. That is the first step. After selecting that, if selected lubricant is not fulfilling the function point of view; second step you say is there may be need to change the lubrication system. Suppose, I selected some sort of molybdenum disulphide, which is cheaper or I selected a graphite, which is cheaper or PTFE, which is cheaper. Now, I have to check am I really getting the right results, desirable results. That is why I say that is there any need to change the lubrication system due to excessive load, if there is excessive load if I

assume the PTFE and I say that there is a load that is very high compared to PTFE requirement, then I will choose a better lubricant, which is a molybdenum disulphide compared to this. We say I will choose graphite and then choose molybdenum disulphide. If the speed is high that may be quite possible we need to think about the semi solid lubricant from the solid lubricant, the speed of operation is more than what is satisfying the solid lubricant or heat up generation is very high that need to be cooled.

So, naturally we need to go for the liquid lubricant or there are too many debris and we require a carrier fluid to carry the debris then we require the liquid lubricant. So, we say the first which choosing a solid lubricant as such because the lowest cost on the debris lubrication requirement, but because of the once we select and we try to justify. Yeah, whether it is really satisfying the entire requirement; it is satisfying the speed requirement; it is satisfying excess load requirement; it is satisfying heat requirement; it is satisfying the debris removal requirement. If any of this says that is not satisfying and we need to change lubrication system then we can refer the table which is given in this case.

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Lubricant Selection

Too much speed	Lesser viscous oil, Oil circulation system with greater oil flow rate, gas lubrication.
High operating temperature	High VI oil with anti-oxidant additives, greater oil-flow rate, Solid lubricants.
Too much debris	Circulation system with filtration.
Requirement of long life	Oil/grease with additives, provision for re-lubrication.
Too much load	More viscous oil, grease, EP additives, solid lubricants

We say that if there is too much speed we provide a lesser lubricant or lesser viscosity oil than they need to be some sort of circulation system of oil or we can think of the gas lubrication. Now, you can think from any angle, any combination, lesser viscosity oil if existing lubrication system is fine then we can say yes otherwise. we can think about the lubrication system which has a low flow rate, thicker oil will be fine with high flow rate low viscosity oil we will prefer and if not satisfying any of this even after selecting this kind of

low viscosity oil is not satisfying the requirement, then we need to think about the gases lubrication.

However if the operating temperature is very high then we should choose high VI at the initial stage we are not choosing a high VI oil it will be costly. Higher and higher VI, cost will be more and more. This oil needs to have oil anti-oxidant additives. If we are purchasing oil, from a market then we need to tell when we require anti additives antioxidant additives in that. We can play with a design also we can go at the high flow rate of the viscosity or high flow rate of low viscosity oil. However, the operating temperature is only high and we really do not require relubrication again and again, because of the compactness or because of the additional system will reduce reliability then, we can again still think about the solid lubricant as it is.

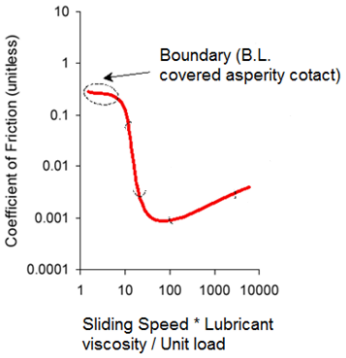
Let operating temperature to be on higher side, initially operating temperature may be what we thought about the 70 degree and we are not choosing. We are choosing some liquid lubricant that is able to reduce say to 70 degree, but it is going to cost us more and more. That is why; we can say now it is going to cost me more, I can think about the solid lubricant. Let operating temperature be 90 degree may be 500 degree, we will change the materials, which are coming in contact we will go by different materials. Sometimes, we feel that too much debris because of the environment or because of the circumstances, and then we need to use a recirculation system with the filtration, with the proper filtration.

We required a particularly longer life, as we say that we do not want to think about replacing oil or oil system easily or quickly. Then we need to think about with additives. Oil complete package additive will enhance the life. Now, finely comes too much load, in addition to any other earlier parameter then we need to think about some sort of additives, which use to reduce a load or shear the load. So, that lesser load is coming on the surfaces.

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Lubrication Selection

- Third Step: If lubricant selection is complete assembly (i.e. I.C. Engine), then it will be preferable to use same lubricant:
  - Single oil reservoir & circulation system can be used.
    - Economic.
    - Reliable.
    - Storage. Lesser chances of wrong usage of lubricant.
  - Due to self compensating behavior of oil viscosity, slightly higher value of viscosity can be selected.



So this is the last slide of this lecturer, we can say that the final selection comes after fulfilling this second step, we say that if we are lubricating the surfaces and there are too many surfaces not only the one pair which we are wearing take an example of IC engine there are many more than twenty troposphere's in IC engine then what will happen. We need to choose a lubricant for each troposphere, which will not justify economic cost reliability. We need to choose only one lubrication system, recirculation system. So, that it can reduce the overall operating cost, inventory cost, an initial cost. So, we choose a lubricant which satisfy or optimize overall performance, here the one negative point we can go ahead we can say that some places we require a low viscosity oil, but other places we require high viscosity oil. I will prefer we will choice a high viscosity oil compared to low viscosity oil to reduce the overall initial cost as well as running cost.

Reason being, high viscosity oil is a self compensation we discussed about, tried back earlier. We say that high viscosity with the hydrodynamic action is happening and operating and one component operating temperature is coming over here or if the operating point is coming over here, in that situation because of the self compensation high viscosity will cause more friction will reduce viscosity there. So, let viscosity plays with itself with this are a self healing process or self adjusting process.

So, with this I will try to close this lecture, and this lubrication model. Now, it is time to deal with some mathematics to quantify what we are saying that it will be moderate load, low load, high load, but we talk about some numbers, our next module is based on that. We will

be doing some sort of mathematical modelling developing some equation, and trying to use those equations. Thank you for your attention.