Tribology

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Module No. # 04
Lecture No. # 17
Liquid Lubricants

Welcome to 17th lecture of video course on tribology. Today's topic is liquid lubricants. In my previous lecture we understood solid and semi-solid lubricants the merits and demerits. Today, we are going to discuss most popularly classification of lubricant or class of the lubricant which is a liquid lubricant.

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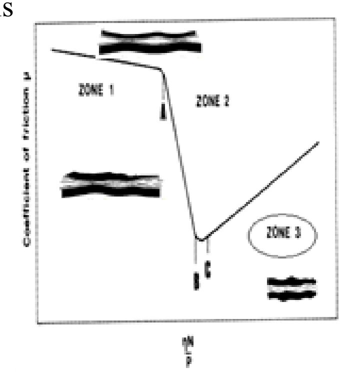
Classification of Liquid Lubricants

- Vegetable (Castor, Rapeseed) oils
    - Less stable (rapid oxidation) than mineral oils at high temp.
    - Contain more natural boundary lubricants than mineral oils
- Animal fats
    - Extreme pressure properties.
    - Availability problem.
- Mineral oils
- Synthetic lubricant
    - Viscosity does not vary as much with temperature as in mineral oil
    - rate of oxidation is much slower
    - cost



Liquid lubricants are classified based on the origin from which liquid were extracted for example vegetables, animals, crude oil, etc. Based on their origin, we classify as vegetable oil (i.e. castor and rapeseed); animal oil (fish oil); olive oil, mineral oil (the most popular and most economic category of liquid lubricant); finally, comes the synthetic lubricant.

We assume that synthetic lubricants are last source of lubricant. If we do not have any other option we will use synthetic lubricants. Every class has it is own merits, and demerits.

Talking about the vegetable oil, it appears to be economic but is very costlier. But, it does not happen to be processing, takes time as well as money.

So, they are not as economic as mineral oils in addition to that they are less stable, thermal as well as oxidation. They deteriorate with increase in temperature and they get oxidized when heated, then viscosity will increase.

And if they thermally degrade then there will be some deposit left with that degradation. Would vegetable oil have its own good quality? Thus contended more contained natural boundary lubricants, they are good additives for high load applications. Coming to the animal fats, one of the major drawbacks about animal fat is availability with stringent norms, government rules. It is very difficult to find out lubricants from animals unless available in one way or another form intentionally we cannot do things.

Very positive point about animal fats is extreme pressure additives or extreme pressure qualities they can sustain very high pressure. That is why they can be used as EP additives. Mineral oil is most popular, most commonly used liberally. And abundant and from cost point of view this will be costly.

Will always vote for the mineral oil. Coming to the synthetic oil see we can design any property in law. And utilize for the commercial purposes only problem is it costs more and more process is involved more and more design involved more and more cost, otherwise any lubricant can be synthesized. Also the lubricant can be synthesized for any applications major advantage of which in the liquid is viscosity, viscosity degradation is very low.

Viscosity index is generally higher on mineral oils, few synthetic lubricant of slightly costlier compare to mineral oil, which can be utilized as common application. Otherwise synthetic lubricant are costlier even two to three four times compare to mineral oil that is why we have restricted application, when they are used, when we do not have any alternative.

One point I missed in this slide is stribeck curve, can you see, and that we already studied this stribeck curve. We say that x axis, there is a sum of a number viscosity of lubricant sliding feet divide by average pressure while. Coming to the x axis coming to y axis, it is a coefficient of friction, we say as Somerfield number increases the of friction decreases to certain level and after that again it increases.

If I think about that all this lubricants I can place with vegetable oil and animal fats. Somewhere in this region or we say that animal fat can be placed in zone one coming to vegetable oil, it can be placed in mixed lubrication oil, mineral oil. Somewhere here in the zone three, and some part in the zone two.

So, based on the condition, based on operating condition we can choose our lubricant or we can mix lubricant, a mineral oil can be mixed with animal fats. Mineral oil can be mixed with vegetable oils or synthetic lubricants also can be mixed with other lubricants based on our application, we can choose proper lubricant based on stribeck curve.

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Vegetable & Animal (Fixed) oils

- fixed oils because they do not volatilize unless they decompose
    - composed of fatty acids and alcohols
    - On oxidation form a gummy substance. This process is known as drying
        - fixed oils which are slow to dry are used for lubrication
- Fixed oils are usually added to mineral oils to improve film formation.
- Ex: Tallow, castor oil, olive oil, fish oils.

One slides on vegetable oil and animal oil such as a big subject processing, how to get, how to do hydrolysis and how to remove carbohydrates the prices contents. And use only content which are desirable, but trick was a complete process, we are not describing that we are not discussing that just discussing a few important points. Sometime this vegetable oil and animal oils are known as a fixed oil resenting they do not vaporize during the operating conditions, they degrade, they decompose.

But, they do not vaporize, they volatize. Volatility is negligible that is why is known as a fixed volume or fixed oils. And as I was mentioned earlier, they are made of the fatty acids and alcohols are congested of alcohols and fatty acids, fatty acid work has boundary additives.

What is the problem with their oxidation they make a gummy substance which will stick to surface, reduced clearance. And the clearance is reduced. Operating condition will change;

the operating condition will change they bring much more difficult situation. So, if I refer to the stribeck curve again say a laser and laser clearance and more and more load will be applied on that and it will turn out to be in stable system or in stable condition.

Now, this last line of a the slide says a fixed oil, which are slow to drive are used for lubrication or in other words fixed oil vegetable or animal oils, which are slow to oxidize would be preferable lubricant compared to rapidly oxidized vegetable oils, rapidly oxidized animal oil.

To reduce oxidization need to be processed properly to avoid more complications we can use fixed oils in mineral oils, some of the example of the fixed oil are that given over here castor oil, olive oil. We have heard number of times fish oil, they are good lubricant additives they are have a good lubricity stick to the surface. So, they can be utilized as additive in mineral oil for lubrication purpose for tribological purposes.

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Mineral Oils

- **Extracted from crude oil.**
- **Consists of hydrocarbons (Composed of *83-87% carbon* and *11-14% hydrogen* by wt.) with approximately 30 carbon atoms in each molecule (composed of straight & cyclic carbon chains bonded together). Also contain *sulphur, oxygen, nitrogen.***
- **Classification based on:**
  - **Sulphur contents: Pennsylvanian oil (<0.25%), Middle east (~1%), Venezuelan (~2%), Mexican (~5%). 0.1% to 1.0% preferred.**
  - **Chemical form: Paraffinic, naphthenic & aromatic.**

Coming to the mineral oil they are generally extracted we process from the crude oil. And major constitute is carbon and hydrogen all is based, that is why we call as a hydrocarbon best lubricating oils and see that carbon percentage is 83 to 87 percent and hydrogen 11 to 14 percent this is by weight.

To get a proper lubrication often they are made with a long carbon chain 30 plus generally recommended for mineral oils in addition to carbon and hydrogen. They often contain sulphur, oxygen, nitrogen, this carbon chain carbon and hydrogen, when they make bond they can form in a straight line.

They can be in branched form on a cyclic form, the property will change the carbon structure is straight chain, behavior will be one kind of the branched carbon chain. Then behavior will change even a cyclic one then behavior will quite change and based on the carbon structure also, they are classified.

Say sometimes mineral oils are classified based on sulphur content. With more stringent regulations we require lubricating oil with low percentage of sulphur is harmful substance it pollute environment. As far low sulphur will be recommended are better anywhere depends on origin of mineral oil from, where it the extracting. They can be classified based on sulphur content pennsylvanian oil, which has a low sulphur percent will be recommended compared to middle east, compared to Mexican.

We say tip of content is lesser than point one percent is suggested by user. Range it can be point 1 to 1 percent beyond. That we need to have some sort of defining process to extract the mineral oils based on mechanical structure based on the branch form or straight form or cyclic form.

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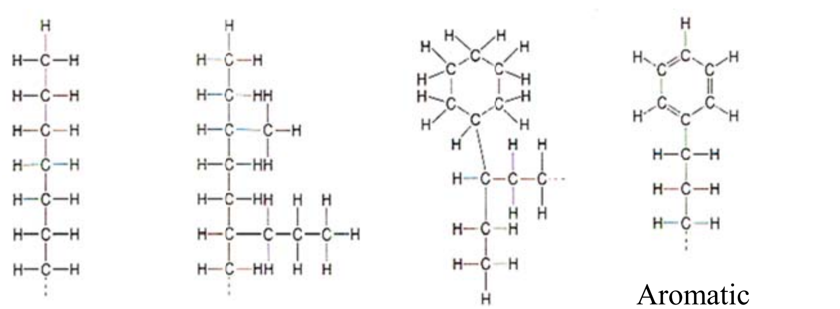
Chemical Forms of Mineral Oils



Straight paraffin 7, 15 +

Branched paraffin 11, 23 +

Naphthene 11, 21 +

Aromatic

Chemical formula C_nH_{2n+2} formula C_nH_{2n}

We divide mineral oils and paraffinic oil and naphthenic oil and aromatic oils one slide is given in the chemical formation you say the chemical forms of mineral oil. You see the simple is straight chain carbon, hydrogen carbon, hydrogen is complete structure. We will be more staple in this case here we have a second figure with branched carbon and carbon is making branched they do not have the same axis, but a lateral axis is also be neutralized.

One important point is that the chemical formula for first figure is a C_nH_{2n+2} hydrogen numbers of hydrogen are two times compare to carbon percentage. Carbon molecules plus 2 while the formula is changed C_nH_{2n} that structure also changes and this kind of thing will be called as naphthenic oils or naphthalene.

While first case it is straight paraffinic oil the branch paraffinic oil I can verify very well that, what are the structure in a first chain or first figure, we find that they are seven carbon molecules of 7 carbons atoms in this case. But, H is the fifteen times I can count this is a 1 2 3 4 5 6 7 and H will be 15 times. But there is one vacancy over here there can be carbon hydrogen it continuous finally, one will be at.

So, this formula will be satisfied 7 carbon hydrogen is 15 and finally, one will come 15 plus 1 as a 16 is two times of seven plus 2. This formula is satisfied similarly coming to the branched one, we have 11 carbon over here and H number of H are 23 plus 1, where is again vacancy over here. There is one more left either it can contain carbon and

hydrogen if it is not containing carbon it will be hydrogen then we will be getting 23 plus 124 ; that means, 20,11 into 2 is 20, 2 plus 2 is 24.

So, both this structures are satisfying paraffinic structure coming to the naphthalene or naphthenic structure, we are able to see they are some complexity coming in this. And because of this structure here both temperature deduces a solidification temperature is slightly higher, they will solidify comparatively some temperature which is higher than paraffinic plus.

I am just reversing, they have a lowest solidification temperature, they will solidify at a lesser temperature compare to the paraffinic oil. So, for low temperature application nothings is good. But, they will not be having those structural or thermal capabilities to sustain high temperature as paraffinic oil. So, both have merits and demerits.

Coming to the aromatic, but we find these bonds are unsaturated, can react easily with other agents other chemical forms. So, aromatic are least preferred compare to the paraffinic and naphthalene. And in this case also we count number of carbon particles or carbon contents compare with H, we will find this is 11 number of carbon, while H are 21 plus 1. There is a one vacancy here it can be occupied by H or carbon for continuation if it is a H. Then it will be 22 that is why 11 into 2 is 22 that formula is satisfied.

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Paraffinic Oils

- Good natural resistance to oxidation. But on oxidation it forms acids.
  - When burnt, leaves a hard carbonaceous deposit.
- Good thermal stability
  - Low volatility
  - High viscosity index (VI=90-115)
  - High flash point
- Pour point higher than naphthenic or aromatic

Some merits and demerits and demerits of paraffinic are you say that paraffinic oil have a good resistance to oxidation, they are more stable against oxygen. But, when they are oxidized they are no useful, they can corrode the environment or corrode the component. Which are in contact in any shell they are not very stable, when abundant they make very hard deposits which can abstract the surface.

So, the lubricants are used to reduce a friction. But, if we slight choose lubricant which is not thermally stable burnt at high temperature. The temperature may be 150 degree, 170 degree, 190 degree. Then they will make deposits and presence of deposits or clearance will reduce in addition, there is a possibility of these hard deposits to act as absorption.

So, we select the lubricant for good reason to reduce friction. But, because of the lack of understanding if you select a lubricant, which is not able to sustain that high temperature which is operating temperature, then they will form deposit on the surface and it is often a case in engine it finds that oils are making deposits on the surface. And it required additives to wash away these deposits. Coming to second point you say that they have a thermal stability. Volatility is a level; they are not as fast grating with temperature.

So, viscosity index is high is 90-115. It is subjective and few mineral oils have lesser than few paraffinic have lesser than 90, we are leaving those exceptions and in addition we have a high plus temperature.

Here it says the power point is higher than naphthenic power point, where the flow starts freezing. And high temperature come between naphthenic, which was mentioned in last line also, that means, for cold applications paraffinic oil will not be as good as naphthenic oils for low temperature applications.

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Naphthenic Oils

- Lower VI (15-75)
- Less resistant to oxidation
- Lower flash points than paraffinic
- Lower pour point than paraffinic therefore good for low temperature applications
- When burnt soft deposits are formed, therefore abrasive wear is lower
- Oxidation leads to undesirable sludge type deposits

Coming to the naphthenic oils, we say they have relatively low VI viscosity index if I am very sure about the operating temperature. If not operating temperature is not going to change significantly. Then I can choose naphthenic oils particularly at lower temperature applications, Naphthenic oils have a good lower power point, compared to the paraffinic oils are good for the low temperature applications. In addition naphthenic oil has one positive point. They do not make deposit as hard as paraffinic oil when they are burnt when naphthenic oils have burnt, they mix soft deposits compared to paraffinic oil.

So, It will be lesser where tendency or they will have a lesser tendency compare to paraffinic oils wet. Because, of the deposits and in addition, when there is oxidation they make a sludge formation clearance will reduce operating condition will change and that is undesirable.

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Multigrade Oils

Most oils on shelf today are MULTIGRADE oils, such as 10W30 or 20W50.

Operate tribo-systems over a wide temperature range. Ex: Aircraft hydraulic oil to be operated from -40 ^{0}C to +150 ^{0}C.

- One grade at 0°F and in a higher grade at 210°F
  - 10W30→ 2100 cP at 0°F & SAE30 at 210°F
  - Lower the first number, better performance in extremely cold conditions
  - Higher the second number better the oil will protect at higher temperatures.
- By adding polymers in mineral oils.

Continuing with mineral oils, do not have very VI (viscosity index) more tendencies towards oxidation at moderate to high temperature, we use a multigrade oils main ingredient is a mineral oil. What we are trying to do?

We are doing some sort of hybridization may be one lubricating oil is good for low temperature application; other lubricating oil is good for high temperature application. You want to hybridize to come up with result lubricating oil is good for low temperature application. As well as high temperature application and interesting thing is that when we go to a market most of time available oils are multigrade oils.

Let us take an example, some sort of classification say that 10W30, W stands for winter and that divides left hand side of that to winter oil, right hand side 10 summers. This w refers to the hot temperature condition or another word, this multi grade oil has something like a SI then characteristics as well as SI30 characteristics.

When we are talking about second example we say that it has 2 characteristics is all SI20 and SI15 characteristics. That is why the multigrade oil instead of one single grade it contains two grades, that is why it says that when tribo systems operate in a y temperature applications. We are prone to use multigrade oils. One typical example is given as an aircraft hydraulic oil, which operates from minus 40 degree centigrade to 150 degree centigrade is quite huge range.

And most of the time mineral oils will not be very useful, may be you require synthetic oils to compare applications. But the cause is a major consideration, and then we can go ahead with some sort of multigrade oil.

And as I said that multigrade oil shows one grade at a 0 degree Fahrenheit and higher grade at the 210 Fahrenheit or 212 Fahrenheit. This is as I mentioned initially the 10W30 W the same example say the very viscosity at 0 degree Fahrenheit and SI30 characteristics as a 210 Fahrenheit.

Whenever this kind of specification comes, we say that lower the first number better will be the results at a low temperature conditions instead of 10. If you use a five that will have a better characteristics at low temperature conditions.

Similarly, add the second number add the left hand side number better will be the performance in higher temperature condition in other words, if I say 10W50 W that 10W50 W will have a better performance of the high temperature compared to 10W30 W viscosity will be highest. So, this is the multigrade oil. Question comes what to make this should I bring that 2 oils SI10, SI30, 50 percent of SI10,50 percent of SI30 makes. If use it, is that up to mark or we should use 30 percent of SI10, 70 percent of SI15 in reality in practice, this kind of approach does not work. Simple mixing will not work. There are number of matrix.

But, one method, the most popular method is adding polymers, adding additives in mineral oil.So, we add polymers in mineral oil to increase its temperature range the question comes, how this mineral oil or polymers is going to work in mineral oil?

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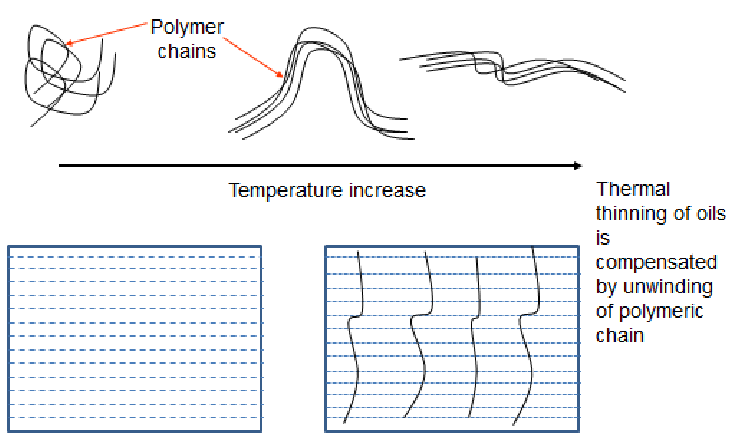
VI improvement using polymeric additives



This schematic given in the slide is a polymer when they are in chain form mixed in mineral oil they have a coiled characteristics. They will be in coil form is roughly. They do not occupy much space they remain in compressed form.

As temperature increases they change their form instead complete form they open up and with further increase in temperature they turn to fibers. And you learnt in a semi solid this kind of fiber gives more resistance to the flow they increase viscosity.

So, this how the polymers work at the low temperature. They will not work or maybe they are added in mineral oil, they will increase slight viscosity because of this addition. But, will not affect to great extent as a temperature increases the viscosity of the oil will increase in other words. If I am using in a mineral oil, mineral oil viscosity will decrease with the temperature, but it is been compensated with increase in viscosity because of this fibers.

So, one negative, one positive, it should give same results change in the temperature is no change in the viscosity to demonstrate that in other field, we have one figure and assuming this is containing lubricating oil.

Now, if the temperature increases. So, these dots are decreasing in other with these dashes are decreasing in with that indicates that viscosity is decreasing with increase in temperature. So, this is increasing temperature sign viscosity is increasing or decreasing in this way. But, as we know there is additive in this which will also open up and with a temperature increases viscosity may be some in this form you can say there is a mineral oil thinned out.

And this kind of fibers they come in between to give more and more resistance to the flow of liquid and to resistance to flow of liquid is known as viscosity. That means, this kind of polymers are acting as viscosity resistance or resistance to decrease in viscosity.

So, I can say thermal thinning of oil is been compensated by unwinding of polymer chain and these are the multigrade oils. And in reality they are not mixed they are not two separate oils. But, they behave like, performance like two great oils like multigrade oils. Now different kind of polymers can be used, which can show three or three grade oil, four grade oil; five grade oil. But, we will be trying to show the performance or the extremes lowest temperature and highest temperature and based on that we can get good results.

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Multigrade Oils

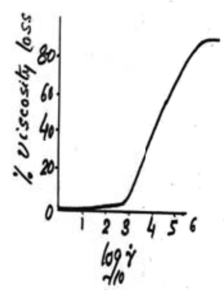
- Effectiveness of multigrade oils is affected by the shear rate, the rate at which the oil has to pass through confined spaces.
- At high shear rate, viscosity of multigrade oil may be little or no different from that of base oil.

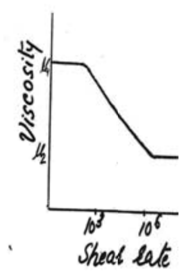
$$\tau_i = \tau_p + \eta_b \left(du/dh\right)^n$$

$$\tau_p = 0.0; \quad n = 1$$

$$\mu = \mu_1 \frac{K + \mu_2 \dot{\gamma}}{K + \mu_1 \dot{\gamma}} \quad ;$$

$$\dot{\gamma} = \sqrt{\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2}$$





Again every advantage is not without any cast or every positive comes for some negative points. That is why we are discussing over here mulitgrade oil have some draw backs. First thing is, that they do not work as Newtonian characteristics. It will show shear dependence with increase in shear rate, viscosity of that oil will decrease. It will show a shear thinning behavior, that is why I said that effectiveness of multigrade oils is affected by the shear rate, the shear rate had which the oil has to pass through confined space nano, space convergence, space oil are pushed, formed at the space. And they will shear they will reduce viscosity.

So that at high shear rate, viscosity of multigrade oil may be little or no different from the base oil. This research shown in this diagram says that when shear rate is low viscosity is high. Actual multi grade oil is working over here. But, as a shear rate is increasing the sudden change in behavior occurs and tries to reduce viscosity, which of the multi grade oil viscosity of the fixed oil or mineral oil in which the polymers are mixed.

This loss in viscosity with increase in shear rate is governed by power law that is why it is given as non-Newtonian fluid. That if the increase in shear rate initially loss of viscosity is not significant, but finite it is not a straight line as shown here. There will be some loss, but there is sudden transition once the transition is over it again reaches to the viscosity of mineral oil from with the multi grade oil for soften or main constitute of the multi grade oil mathematically.

This can be expressed the way we have treated this as a semi solid lubricant, see shear strength interface, shear strength due to the multi grade oil can be again given by τ_I as initially, some shear as strength is required to flow it may be zero also and viscosity plus this is going to change here. And will be where multi grade oil it may be 0.8 0.85 0.9 depends on the kind of polymers mixed with that.

Sometime we use this lubricant or this lubricant relation he says that there is a shear stability constant k, shear rate is given it can be one dimensional it can be two dimensional. What we have considered previous examples mostly, we assume what relative velocity or sliding velocity is only in one direction, that was x direction that is why the velocity was expressed in by u.

However, for general application when velocity is a mu and x direction, as well as a z direction then shear rate in y direction can be expressed by first term. And then shear rate in second or z direction can be expressed for second term is this shear rate can be substituted, whatever the value we know if operating conditions are known to us. We can substitute here is viscosity had a high shear rate it is more like assen diagram for the fatigue loading.

Initially μ change then suddenly change and after that reaching to one new formation the constant value. If the mineral oil does not depend much on shear rate it works as a neutron fluid or we can say in other words also this mineral oil is mixed with a polymer additives can show two kinds of neutron fluid high viscosity, neutron fluid initially. If the low shear rate and low viscosity, neutron fluid shear rate can be in between transition.

Transition behavior can be obtained by using this relation if the viscosity or with the shear rate is a lesser than this limit. Then it will be high viscosity neutron liquid and if shear rate is more than this limit. That will be high viscosity, low viscosity neutron fluid in between the shear rate, whatever the in this is the example, we are saying the 10 is to 3 is to 10 is to 6. But, not necessary for every oil will be 10 is to 3 into 10 is to 6. It can be different.

Now, if I use a high shear rate in this case, then relation will be how was turning out to be equal to the viscosity μ_2. Because, μ_1 will be cancelled out and if the low shear rate, then it will be the μ_1 we can substitute. And we can find it depends whether this parameter is very high or low you assume the shear stability parameter is zero. That means, this multigrade oil is working with a viscosity equal into μ_2.

Now, if k value is very high, then this multigrade oil will remain for the longer duration for much higher shear rate. The word shear stability parameter had the higher value better will be result. Even if I use a multigrade oil 10W40 in one case it turn out to be 20000, in other case for the same specification K turn out to be 50000.

So, in that situation we say that 50000 value of k equal to 50000 will be preferable option preferable multigrade oil compare to 20000 value of K. So, based on this shear a stability parameter we can choose multigrade oil how was the specification both the oils will be 10W40 will not be able to distinguish much from one component to other component, that distinguishment can come using shear stability parameter.

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Synthetic Oils

- Expensive, but applied where mineral oils are inadequate.
  - Oxidation & viscosity loss at high temperature
  - Combustion or explosion
  - Solidification at low temperature

NOTE: Jet Engine. $t_{ambient}$ < -120ºF. 60000 shaft rpm, and 500ºF exhaust temperatures proved too much for mineral oils.

- Synthetic oils are engineered specifically in uniformly shaped molecules with shorter carbon chains which are much more resistant to heat and stress.

Now, final one comes after a liquid lubricant is synthetic oil. That major thing is expensive. Because, the steam designed for major companies who have a very high production, overall cost may come down. Because, of the design cost will be only one time after that one fabrication or synthesis cost. But, for the new applications this will turn out to be very costly affair.

And it says that because of the cost this oils should be used whenever mineral oil are inadequate either they have this more tendency of oxidation. And there is more tendency of viscosity loss, there is more tendency of explosion, there is more tendency of solidification in those situations. Synthetic oil should be utilized how was the mineral oils are very cost effective those oil should be utilized with on either pure form or with some mineral some sort of additives to give extra properties.

Typical situation where the synthetic oil, are used is a given as jet engine the temperature, we can see the minus 120 Fahrenheit operating speed very high. The 60000 plus and exhaust temperature of that engine is more than 500 Fahrenheit in this situation. Mineral oil with all kind of additives may not give very good results, may not give desirable results to us.

And that is why say synthetic oils are engineered. Will be uniformly shaped molecules that is why will be having much more than mineral oils and they are generally made with a low carbon chain. So, that if they have more heat and stress stability they have much more strength. However, their property will go down with low chain that means good for high speed application. If there is more possibility of hydrodynamic action for high temperature separation is not a problem. But, the high temperature is problem based on requirement is it can be selected?

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- **Polyglycols (Polyalkylene glycol)**

  Originally used as Brake fluids. VI = 200. Absorb water.

  Distinct advantages as lubricants for systems operating at high temperatures such as furnace conveyor belts, where the polyglycol burns without leaving a carbonaceous deposit. Used in textile industry.

- **Esters**

  Reacting alcohol with inorganic acid.

  Better (in reducing friction, resisting oxidation, prolong draining period, volatility) than mineral oils.

  Costs only a little more than mineral oils.

There are few synthetic oils, which we are described here. However, there is a complete subject on the synthetic oils in chemistry. First common category is a polyglycols, VI is almost 200. And they have been utilized in brake as a brake fluids we try to utilize this kind of polyglycol in our magnetic bearing. Where desire was low temp low lubrication requirement and film thickness was maintained by the magnitude repletion.

If we would have used high viscosity oil they would have been much more shear sharing of that oil much more heat generation. But, we use brake fluids which have low viscosity and what we used viscosity equal to the 2cst at 100 degree centigrade, we run that set for the 6000 RPM for the almost 3 to 4 hours. And we found non uniform signal degree temperature wise reason being magnetic limitation was there and even though, there was a problem created for the high dynamic action.

But there was a clear separation between two surfaces. So, for high speed applications this kind of oils can be utilized, we have a low viscosity which is always a desirable for high speed applications. And another thing is that they have good cooling capabilities. So, which are desirable in addition if they have a high temperature application, if they start burning they do not leave any debris they do not leave any deposits. So, they are clean liquids therefore, you do not show they were those kind of lubricants were there in the dominant. So, they can be utilized for the textile industries if the cleanliness is the prime required.

A kind of low cost lubricants synthetic lubricant are the Easters can be made by alcohol in an in organic acids they are much cheaper than other synthetic lubricants. But, they show a good performance they show the lesser the friction lesser resister lesser oxidation is more resistance for the oxidation.

And because of that good resistance flow oxidation, their draining time, their draining period is large or we say that, they do not require a sequent replacement draining period, during draining duration is large they do not vaporize easily as the mineral oils of I mentioned. And they are less costly compared to number of other synthetic oil that is why they are popular I can say that they have a cause more than mineral oil. But, not so significantly.

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- **Silicon:**

  VI 300. Chemical inert. Poor boundary lubricant. Low solubility. Space application, HIGH PRODUCTION COST.
- **Perfluoropolyalkylether:**

  Good oxidation & thermal stability. VI= 200. In vacuum used for thin film lubrication.
- **Perfluoropolyethers**

  High oxidation (320°C) & thermal (370°C) stability.

  Low surface tension & chemical inert.

This is marginal even silicon oil is very costly liquid, very good high wear, much more resistance temperature, thin viscosity does not decrease that much in addition they are chemical inert.

So, wherever there is a tedious or there is a composing environment they are high temperature applications and reactive environment, we can choose silicon oils. But, they have a low boundary additives or we say of boundary performance is low there oiliness level is negligible. They do not strict to the surface they can be used as a lubricant see if there is a hydrodynamic action.

They should be used if cost permits most often, this kind of lubricants are used for this space applications keep in mind silicon oils or always required with good design, good understanding of the system. If we do not have very good design assume the lubricating oil is going to deal with the entire situation that will not work particularly with a silicon oils.

There are two similar kind perfluropolyethers their VI is high they have very good a thermal. And oxidation stabilities even can be used in vacuum application can see perfluropolyethers the temperature limit is 320 degree centigrade same as silicon oil they are also chemical inert. They will not react with environment easily. So, we have good lubricant high temperature lubricants and cheaper than silicon oils.

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Few Remarks on usage of lubricants

- Grease: provides excellent protection against environmental contamination.
  - restricted to a speed of 2 m/s for the reason of inadequate heat dissipation
- Liquid:
  - Low viscosity oils have low fluid friction losses and consequently low heat generation.
    - Carry away heat.
    - pressure for greater dissipation of heat as well as to ensure complete separation of surfaces.
  - Under high loads and slow rubbing speed a hydrodynamic film cannot form, hence mineral oils are combined with fatty oils to give a boundary lubrication layer.

So, this kind of lubricant be selected as per our wish, as per our application with the cost is permitting us there few remarks. When we choose lubricants first remark is in the grease good point is that it attaches to the surface it covers the surface.

So, gives a good production against the environmental contamination. But, they are restricted to the speed application. Higher the speed application they will be very high thinning of the grease or we say that there will be bleeding of the grease. That is why the speed limit many times is the two meter per second except the few rolling bearings or rolling element bearings if the speed limit is slightly larger because of the rolling action. But, in sliding condition major reason given for this is inadequate heat dissipation their thermal conductivity is negligible. They cannot dissipate they conduct heat properly they can't convert heat properly.

So, this kind of grease will not be having mode of heat transfer coming to liquid side you say that prefer low viscosity oils. Major reason, there will be lesser shearing if the neutron fluid, we can say shear stress in purposely to viscosity. Lesser the viscosity, lesser will be shear resistance. Lesser the shear resistance clear solved the friction force lesser the friction force lesser will be the heat generation.

So, low viscosity oil should be preferred compared to high viscosity oil provided minimum film thickness is maintained. Now, this low viscosity oil are also preferred from the cooling point of view, that is why they can carry the heat in addition they are preferred from the heat, pressure point of view, if we as trying to levitate once surface over other surface or keeping the separation.

Between the surfaces sometime we force speed the lubricant and pressurize the lubricant between the two surfaces in that those situation again. There low viscosity lubricant will be preferred because, high viscosity will give more resistance to pumping and more resistance should be pumping means there will be more power consumption.

So, cost of power loss will be increasing we say power loss will increase the cost will increase. However, if this low viscosity oils are not able to give good performance because, of the high load condition or slow rubbing speed, when the hydrodynamic reaction is not made, then we can use additives or we can add additives in this case mineral oils can be combined with boundary additives or we say can be attached or mixed with e p additives together to get desirable results for us.

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GAS Lubrication

- Gas– Air, Nitrogen, and Helium
- Temperature range– (-200°C) to (2000°C). No vaporization, cavitation, solidification, decomposition.
- Very low viscosity (1000 times less viscous than even the thinnest mineral oil), therefore ultra low friction. Possible high speed.
- Cleanliness.
- Seal requirement ?
- Very low load capacity. Low damping. Ultra low film thickness.
- Smooth surfaces & very low clearance (to maximize load capacity & minimize flow rate) needs a specialist designers & manufacturer (close tolerance).
- Less forgiving of errors in estimating loads or of deviations from specifications during manufacture and installation.
- Solid lubricants for air bearings???????

Final one after liquid lubricant comes gas lubrication; we have only one slide because gas is not intent lubricant unless it is pressurized.

So, that when we are talking about the gas it can be anything, it can be environmentally available air, it can be nitrogen, it can be helium. We know helium has good leviting capacity major or main important point of the air is a temperature range. Temperature range may start minus 200 degree centigrade to 2000 degree centigrade. And major thing is this no vaporization that is advantageous to us.

They will not have cavitation when we discuss application on the liquid lubricant will discuss about the cavitation also. There is no problem related to solidification unless the temperature is very low.

And there is only composition also. So, we are aware of all those problems related to viscosity. It as a very low viscosity, will not give much problem relatively clean. They do not require seal unless we pressurize we send we pass air or helium or nitrogen as some pressure of course. If the environment pollution is the issue curve related then seals will be requirement.

But, not from operating point of view, but there are some drawbacks we say this kind of lubrication is effective, when the low requirement is not very high, applied load is very low, we do not require any damping or there is no vibration related problem.

Even ultrathin film thickness is sufficient to separate the surfaces. That means, we required very good surfaces of the tribo surfaces, now this is imposing major design problem if surface needs to be very smooth. And by the way, if they come in to contact there will be very high adhesion. So, gas lubrication required extreme optimization with all calculation of uneven days or we say that in the entire situation you should be working. How it will turn out to be instable situation with slight change in the load.

It may contact or surface may come together or, one against each other and there will be high adhesion between surfaces that will be problematic. That is why we say that it is lesser forgiving of the errors in estimating the load, the load estimation is not proper then there will be problem. These bearings are highly optimized once; we have a thorough understanding of the complete system. Load, speed, temperature variation, in the load vibration, in speed then only, we should be able to utilize air bearing.

Talk about rheometer, where we want to find out the actual measuring torque or whatever the torque in accumate, we want to measure that or torque resistance given by fluid, we required extremely good bearings in those situation. These at bearings can be replaced a very sensitive towards. The operating condition that is why once we know we have thorough understanding of systems.

Then only we should utilize this sometimes we tolerate this kind of transit conditions. We mix solid lubricant of course. Mixing solid lubricant does not mean that you have to mix in gas. What we apply coatings on solid lubricant, coating on the surface 15 to 20 micron coating, that will be extra smooth surface even the two surface are coming in contact. They will not wear away easily because of the solid lubricant, which because of the junction formation will be low, interface low shear strength or junction.

That will be good option may be mixed solid lubricant with air lubricant or apply solid lubricant on the surface and then operate on air related operation either air static aerodynamic conditions.

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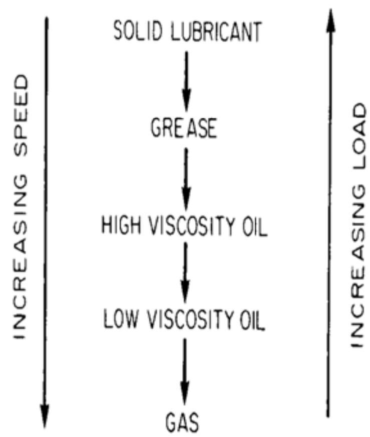
Selection of Lubricant Type



- Major factors:
  - Load
  - Speed

  Temp. Rise

$$T_s \propto \frac{\mu F V}{A K}$$

- Minor Factors
  - Environment temperature
  - Sealing requirements

Now, there is an overall selection criterion for choosing the lubricant. The slide shows one arrow which is indicating the increase in speed, just opposite side there is one arrow which is increasing the load, that means, increase in load and speed. They are contradictory. Higher speed will give different trials higher load will give different trials and they are always in contradiction.

See, this meaning at there is a very high load and load lowest speed application, we should choose a solid lubricants; after that number of grease comes, we say that moderate loads and moderate speed. Similarly high viscosity oil can be used for moderate load moderate to low speed; viscosity oil is for low load lowest speed.

Coming to the gas, this is used for very low load and very high speed. Based on this, we can choose lubricant whether we half for the solid lubricant grease semisolid high viscosity oil low viscosity oil or gas. That is why we say that whenever the selection comes two major criteria will be the load as well as speed.

Both the criteria pointing towards the temperature rise. A lowest speed will give high friction, high heat generation, and high temperature rise. Same thing happens at high speed again the temperature rise will be larger.

And this can be given operating temperature. Higher coefficient of friction is high temperature high temperature means, we should go for the low viscosity oil or the gas high force again high temperature. Then the situation we need to tolerate there, we need to tolerate combine to lubricants high velocity again we have high operating temperature.

So, we choose a lubricant accordingly the two factors in addition to this mu half and v are given as area, larger area lesser will be the operating temperature. Because, there will be more dissipation area, will be available heat will be dissipated easily in addition to that last parameter comes that is a k. That is conductivity the mating surface have a good surface thermal conductivity than operating temperature will be low. It there any other method we can see if the operating temperature will be low? And we can choose low viscosity oil of the gas if high temperature which is going to reduce a viscosity to oil again in that situation we choose a high viscosity.

So, it is a slightly complex more note we should choose semi solid and solids. But, there is going to increase the temperature increase in temperature. If it is a deducing this there is a viscosity of the lubricant. Then we should choose some sort of additives and this in indicates that study of the additives along with kind of lubricant is essential. So, that will be our next lecture on relating to the additives will discuss about the lubricant additives. Thanks for your attention.