MACHINERY LUBRICATION SPECIALIST CERTIFICATION COURSE PREPARATION COURSE HANDBOOK

R.L. Thibault
Lubrication Training& Consulting
Houston, Texas

CONTENTS

INTRODUCTION

Level I Machinery Lubrication Technician (MLT) Certification Requirements

To become certified, an individual must meet the following requirements:

- **Education and/or Experience** - Candidates must have at least two years education (post-secondary) or on-the-job training in one or more of the following fields: machine lubrication, engineering, mechanical maintenance and/or maintenance trades.
- **Training** - Candidate must have received at least 16 hours of documented formal training in machinery lubrication. The MLT training class meets this requirements.

The exam is closed book and it consists of 100 multiple choice questions. Bellow you will find the MLT I Body of Knowledge with the subject areas being tested, as well as their corresponding percentages:

I. Maintenance Strategy (5%)

A. Why machines fail
B. The impact of poor maintenance on company profits
C. The role of effective lubrication in failure avoidance

II. Lubrication Theory (10%)

A. Fundamentals of tribology
B. Functions of a lubricant
C. Hydrodynamic lubrication (sliding friction)
D. Elasto-hydrodynamic lubrication (rolling friction)
E. Mixed-film lubrication

III. Lubricants (15%)

A. Base-oils
B. Additives and their functions
C. Oil lubricant physical, chemical and performance properties and classifications.
D. Grease lubrication
   1. How grease is made
   2. Thickener types
   3. Thickener compatibility
   4. Grease lubricant physical, chemical and performance properties and classifications.

IV. Lubricant Selection (15%)

A. Viscosity selection

B. Base-oil type selection
C. Additive system selection
D. Machine specific lubricant requirements
   1. Hydraulic systems
   2. Rolling element bearings
   3. Journal bearings
   4. Reciprocating engines
   5. Gearing and gearboxes
E. Application and environment related adjustments.

V. Lubricant Application (25%)
A. Basic calculations for determining required lubricant volume.
B. Basic calculations to determine re-lube and change frequencies.
C. When to select oil; when to select grease.
D. Effective use of manual delivery techniques.
E. Automatic delivery systems.
   1. Automated deliver options.
      a. Automated grease systems
      b. Oil mist systems
      c. Drip and wick lubricators
   2. Deciding when to employ automated lubricators.
   3. Maintenance of automated lubrication systems.

VI. Preventive and Predictive Maintenance (10%)
A. Lube routes and scheduling
B. Oil analysis and technologies to assure lubrication effectiveness.
C. Equipment tagging and identification.

VII. Lube Condition Control (10%)
A. Filtration and separation technologies.
B. Filter rating.
C. Filtration system design and filter selection.

VIII. Lube Storage and Management (10%)
A. Lubricant receiving procedures.
B. Proper storage and inventory management.
C. Lube storage containers
D. Proper storage of grease-guns and other lube application devices.
E. Maintenance of automatic grease systems.
F. Health and safety assurance.

In order to register for ICML exam, candidates should submit the application form online at: www.lubecouncil.org: click on the link on the left of the page "Apply for exam" and then, "application form" or just follow this link: https://www.payitsecure.com/ICML/enrollment_form.asp. The application fee is $200.

Section 1
LUBRICATION FUNDAMENTALS

Lubricant Functions

Lubricants:

Clean

Cool

Seal

Reduce friction and wear

Protect against rust

And sometimes act as a dielectric and transmit power or dampen shock.

Reduce friction and wear
All surfaces are rough when examined under a microscope. They are covered with minute peaks and valleys called asperities. When the peaks come into contact each other, they momentarily weld together, causing friction, heat and wear. Lubricants form a slippery film that prevents the peaks from welding together.

Carry away heat
When the asperities weld and release, the heat at that point can exceed 1000°F. Oil absorbs this heat and can be circulated to a cooler. In some systems, the heat passes from the oil, through the sides of the equipment or oil reservoir and into the air.

Seal against contaminants
Greases are particularly effective at sealing against contamination from foreign liquids and solids. The grease in the wheel bearings of your car helps prevent contamination from puddles and road dirt.

Prevent rust and corrosion
The presence of a film of lubricant on bearings and gears protects them from rusting by preventing their contact with air and moisture. Rust prevention can be enhanced by the addition of rust inhibiting additives.

Corrosion occurs when oxygen or other corrosive material attacks a metal surface. Rust is the same type of reaction on ferrous (iron-containing) metals.

Remove contaminates
Contamination can come from the outside environment, and it can also be internally generated. For example, cement dust can get into a gearbox from the outside. The gears, as they wear, produce metal particles. If there were no fluid to carry the contaminants away, these abrasive particles would damage gears and bearings.

In gasoline and diesel engines, detergent-dispersant additives suspend dirt, sludge and oxidation products and carry them from the crankcase into a filter. The flushing action of lubricants in removing solid contaminants from between bearing surfaces is most important in the metalworking industry.

Transmit Power
Hydraulic systems are used everywhere – from lifting automobiles in a service station, to raising the boom on a crane, to controlling the flaps on a jet liner. Fluid is used to transmit power where it’s not possible to use electrical, mechanical or pneumatic energy.

Act as a dielectric fluid
Imagine being lifted in an aerial lift device (also known as a cherry picker or bucket truck.) Wouldn’t it be a good idea for the hydraulic fluid to resist conducting electrical current? It may be the difference between life and death in case the truck inadvertently bumps into a live electrical wire.

Desirable properties of a good dielectric fluid are:

- High dielectric strength
- High flash point
- Good oxidation stability
- Low volatility
- Good heat transfer properties

Dampen shock
Petroleum and synthetic fluids are often used in shock absorbers.

Lubrication Regimes

Lubricants primarily operate in the following regimes:

- Full fluid film

Boundary

Mixed film

Elasto-hydrodynamic

Hydrodynamic lubrication (also known as **full fluid film**) occurs when the lubricant film is sufficiently thick enough to separate the moving surfaces completely. Hydrodynamic lubrication can be found in plain bearings such as the crankshaft bearings in an engine. Once the engine is started, the molecules clinging to the surface of the metal are drawn between the sliding surfaces. They form a "hydrodynamic" wedge of oil and keep a constant fluid film between the bearing and the crankshaft. Since metal does not contact metal, the viscosity of the fluid is more influential than additives.

Hydrostatic lubrication (another type of **full fluid film**) occurs when the oil is supplied to a bearing with enough external pressure to separate the sliding surfaces. An example is the oil supplied with a high pressure pump to float a shaft to minimize friction at start up. This technique is used on large turbines during start up.

Boundary lubrication – Under high pressure, there can be metal-to-metal contact. As gears mesh, the teeth contact each other, and the oil is squeezed out. Chemicals can be added to the oil that reacts (under locally high temperatures) with the metal surface to form a slippery metallic-soap type layer. This allows the asperities to slide over each other instead of welding together. These chemicals are commonly sulfur-phosphorous extreme pressure additives.

Mixed film lubrication – Some applications are mostly lubricated by a full fluid film, but may also have some metal-to-metal contact. In this case, you would use a fairly viscous oil to keep the metal parts separated, but also use a fatty material or extreme pressure additive to protect the surfaces from metal-to-metal contact. These additives act like a molecular "carpet" to reduce friction.

An example of mixed film lubrication would be steam cylinders, where steam washes the oil off of cylinder walls. The lubricant often contains acidless tallow or stable fatty materials that coat the walls to prevent lubricant wash-off.

EHL – Elasto-hydrodynamic lubrication – A rolling contact bearing can generate very high pressures between the rollers and the race. Since the rollers are moving so fast, there is no time for the oil to get squeezed out from underneath the rollers. The fluid is not very compressible, so the rollers actually deform to allow the fluid to have enough room to separate the metal parts.

Load has little effect on film thickness because at the pressures involved, the oil film is actually more rigid than the metal surfaces. Therefore, the main effect of a load increase is to deform the metal surfaces and increase the contact area, rather than decrease the film thickness. The EHL regime also takes place in gear sets as the fluid is trapped between the contacting surfaces, or pitch line, of the gears.

“Elasto” refers to the metal’s ability to “flex”
“Hydro” refers to the fluid
“Dynamic” refers to motion

Lubricant Physical Properties

Viscosity, which measures oil’s resistance to flow, is the most IMPORTANT property of a lubricant. Water has a relatively low viscosity; molasses has a much higher viscosity. However, if you heated molasses, it would get thinner. Likewise, oils also get “thinner” as they get hot. Viscosity has an inverse relationship with temperature.

As pressure increases, the viscosity of oil increases, too. Therefore, the viscosity of oil in service varies with its temperature and pressure.

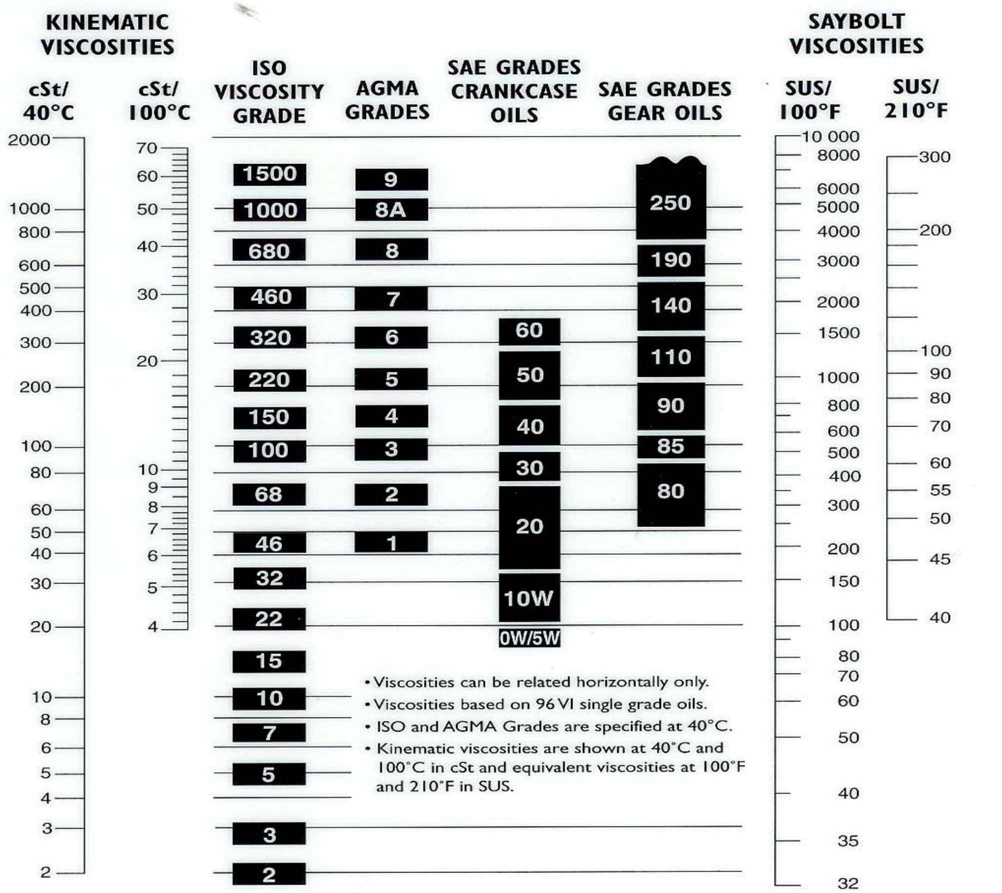
The viscosity of industrial oils is generally reported at 40°C. The International Standards Organization uses this as the standard for its ISO VG grading system that ranges from ISO VG 2 to ISO VG 1500. The ISO VG is defined as the midpoint of a range that is ± 10%. For example, a hydraulic fluid with a viscosity of 31.5 cSt at 40°C has an ISO VG of 32. This is illustrated in the following table

ISO VG	MID-POINT	LIMITS, KV 40°C		ISO VG	MID-POINT	LIMITS, KV 40°C	
	KV 40°C, mm^2s^{-1}	Min.	Max.		KV 40°C, mm^2s^{-1}	Min.	Max.
ISO VG 2	2.2	1.98	2.4	ISO VG 100	100	90	110
ISO VG 3	3.2	2.88	3.52	ISO VG 150	150	135	165
ISO VG 5	4.6	4.14	5.06	ISO VG 220	220	198	242
ISO VG 7	6.8	6.12	7.48	ISO VG 320	320	288	352
ISO VG 10	10	9	11	ISO VG 460	460	414	506
ISO VG 15	15	13.5	16.5	ISO VG 680	680	612	748
ISO VG 22	22	19.8	24.2	ISO VG 1000	1000	900	1100
ISO VG 32	32	28.8	35.2	ISO VG 1500	1500	1350	1650
ISO VG 46	46	41.4	50.6	ISO VG 2200	2200	1980	2420
ISO VG 68	68	61.2	74.8	ISO VG 3200	3200	2880	3520

Lubricating oils can range from very low viscosity like solvents and kerosene used for rolling metals, to high viscosity fluids that barely flow at room temperature, such as steam cylinder oils or gear oils used in sugar mills.

Crankcase oil and passenger car and truck gear systems viscosities are measured at 100 C. The following viscosity chart illustrates the relationship between the various viscosity systems

Viscosity Grading Systems



Rule-of-Thumb: The comparable ISO grade of a given product whose viscosity is greater than 100 SUS at 100°F if known can be determined by using the following conversion formula:

SUS @ 100°F ÷ 5 = cSt @ 40°C

Viscosity Index: This is an empirical number that indicates the effect of change on the viscosity of a lubricant. A lubricant with high viscosity index does not thin down very fast as it heats up. It would be used for oils that are used outdoors in summer and winter. Multi-viscosity engine oils have a high viscosity index. It is calculated by measuring and plotting the viscosities of oil at 40 C and 100 C and determining the slope of a line. The steeper the line the more oil viscosity changes with temperature; therefore thee lower the viscosity index . A high viscosity index is desirable in oil

Density – the mass per unit volume of a substance can be expressed in pounds per gallon, kg/m
or g/cc. It is a measure of how well a substance floats on top of water
(or sinks below the surface.) Water has a density of approximately 1 g/cc at room temperature. Petroleum fluids generally have a density of less than 1, so they float. Oil slicks float on the surface of a puddle. Water drains in reservoirs are positioned at the bottom of the reservoir. The lower the specific gravity, the better the oil floats. Oil with a specific gravity of 0.788 floats very well.

The density of oils decreases with temperature; they float better as they heat up.

Density of petroleum products is often expressed as API gravity so it can be expressed in whole numbers rather than in small decimals. The API Gravity of water is 10. Since API Gravity is the reciprocal of specific gravity, the higher the API Gravity, the better it floats; therefore oil with an API Gravity of 30 floats very well.

Pour point of oil is the lowest temperature at which it will pour, or flow, when chilled without disturbance.

Film strength is a measure of a fluid's lubricity. It is the load carrying capacity of a lubricant film. Film strength can be enhanced by the use of additives. Many synthetic oils have greater film strength than petroleum oils.

Flash point is the temperature at which the vapors of a petroleum fluid ignite when a small flame is passed over the surface. In order for combustion to occur, there has to be a certain air/fuel mixture. If there is too much air, the mixture is too lean – there's not enough fuel. If there's too much liquid, it essentially suffocates the flame. The flash point is the temperature where there are enough molecules bouncing around in the air above the surface to produce an air/fuel mixture that will burn (if there is a spark to ignite them.)

The flash point is directly related to evaporation rate. A low viscosity fluid will generally evaporate faster than high viscosity oil, so its flash point is typically lower.

For safety, it is a good idea to choose oil that has a flash point at least 20°F higher than the highest operating temperature in the equipment.

Fire point is the temperature which supports combustion for 5 seconds.

Oxidation resistance affects the life of the oil. Turbines and large circulating systems, in which oil is used for long periods without being changed, must have oils with high resistance to oxidation. Where oil remains in service only a short time or new oil is frequently added as make-up, those grades with lower oxidation resistance may serve satisfactorily.

The rate of oxidation of petroleum oils tends to double for every 18˚F (10°C) rise in temperature
In other words, for every 18˚F(10°C) that you raise the temperature of a system, expect to change the oil twice as often. Another way of stating this is for every 18˚F decrease in oil temperature, oil life is doubled.

Water separation – Industrial oils must separate readily from water whereas we don't water to separate from engine oils and accumulate in the crankcase. We want the water to flash off at the high engine temperatures. The separation of oil from water is called demulsibility. Water can cause rust, corrosion and wear, among many other detrimental factors. Mixing industrial with small amounts of engine oil will ruin the demulsibility of the oil.

In general, circulating systems require oils that demulsify well. Once-through systems do not require demulsifiers because the oil doesn't recirculate and collect enough water to cause rust. Demulsifiers are not necessary if the system is hot enough to boil off any water. Emulsions are important for fire resistance and metalworking cooling.

Rust and corrosion protection – When machinery is idle, the lubricant may be called upon to act as a preservative. When machinery is in actual use, the lubricant controls corrosion by coating lubricated parts.

Grease Consistency – Consistency is determined according to the depth to which a sharp, pointed cone will penetrate the grease when dropped from a certain height. This is called grease *penetration* and is reported in tenths of a millimeter. The NLGI has established consistency grades based on the penetration of the grease. 000 is so soft that it is considered semi-fluid and 6 is so hard that it is almost a solid block. Most multi-purpose greases are NLGI 2. Centralized lubrication systems typically recommend NLGI 1 or 0.

NGLI Consistency Number	ASTM Worked Penetration at 77F (25C)
000	445 to 475
00	400 to 430
0	355 to 385
1	310 to 340
2	265 to 295
3	220 to 250
4	175 to 205
5	130 to 160
6	85 to 115

The percent and type of thickener have the greatest effect on grease consistency, although, in application, the temperature and shear stability of the grease can also affect its penetration number.

Grease dropping point is the temperature at which a drop of grease falls from an orifice. It is the temperature at which it passes from a semisolid to a liquid, which is essentially the point at which it melts. Remember that the dropping point is NOT the upper operating temperature of the grease. You do not want to be using grease close to the temperature at which it will melt. Normally use grease 100-150˚F below the dropping point.

Grease pumpability is the ability of the grease to pump through a long line. Two greases that may be pumped with equal ease at room temperature may not pump the same at lower temperatures. This is a result of the types and proportions of oils and thickeners in the two greases.

Grease water resistance is important for wheel bearing applications and equipment with high exposure to water. Greases with calcium, aluminum, lithium and most complex soaps have better water resistance than greases made from sodium soaps.

Grease stability and apparent viscosity can make a difference in applications where there is rubbing or pounding motion that can destroy the thickener of some grease. They may change their consistency as a result of shear stress. For this reason, grease penetration is often measured after the grease has been worked with a paddle for 60 strokes, and then after it has been worked for 10,000 strokes, to anticipate the possible effects of shear. Since greases are non-Newtonian, the viscosity changes with rate of flow and is called apparent viscosity.

Grease resistance to oxidation – Both the oil and the fatty constituents in grease tend to oxidize. When grease deteriorates, it sometimes acquires a rancid odor and a darker color. Although the organic acids that usually develop in the grease are not necessarily corrosive, they sometimes soften or harden the grease. Depending on their ingredients, additives, and processing, various greases have different levels of oxidation resistance.

Grease texture describes greases by how they look or feel, including such terms as smooth, buttery, fibrous, stringy, tacky, rubbery, etc. Color is also a grease property. Greases are also categorized by how well balls or rollers channel through them. The thickener in good channeling grease tends to stay near the outside of the race and does not slump back into the way of the balls or rollers to cause drag.

Grease base oil viscosity is essential because it has a great bearing on the successful use of the grease at different speeds, loads and temperatures. Since the oil component of the grease does most of the lubricating, the same principles apply to choosing the base oil of the grease as to lubricating oil. High temperatures, high loads and low speeds require high viscosity base oils.

Grease resistance to oil separation can keep oil from dripping out of grease. In general, a small amount of the oil is designed to separate from the grease because it is the oil component that does most of the lubrication. It is common to find a small puddle of oil floating in a depression of the grease's surface. If this happens, mix the oil in, or decant it. Either action will not affect the performance of the grease.

If the oil separates excessively, the grease may harden.

Types of lubricants and their applications

Petroleum oils account for most of the two general categories of industrial and transportation lubrication. They are refined from crude oil, which, as everyone knows, was formed from billions and billions of tiny microorganisms that converted over time and pressure to oil. The term hydrocarbon simply means that it is predominantly comprised of hydrogen and carbon, although there are small amounts of other elements such as sulfur and nitrogen.

The two principle types of petroleum oils used for lubricants are paraffinic and naphthenic. When you think of paraffin, you think of wax. That gives you a good idea of the strengths of paraffinic oil. Wax is an excellent lubricant; it is slippery and quite stable at high temperatures. It is ineffective at low temperatures because it turns solid. For this reason, paraffinic oils are recommended for most industrial and transportation lubricants, except where they run at cold temperatures. Another characteristic of wax is that it leaves very little residue when it oxidizes, but the small amount of residue is hard and sticky.

Naphthenic oils are not waxy, so they can be used to very low temperatures. While they tend to leave more deposits than paraffinic oil, what is left behind is soft and fluffy. Compressor manufacturers often prefer naphthenic oils because the deposits get blown out with the compressed air rather than building up on discharge valves. Naphthenic oils are also used in many refrigeration applications because of their good cold temperature properties.

Physically, paraffinic oils can be distinguished from naphthenic oils because of their higher pour points and lower density. Paraffinic oils typically weigh between 7.2 and 7.3 pounds per gallons, while naphthenic oils are slightly heavier. Be careful about characterizing the base stock of a formulated product based on physical properties because additives can strongly affect physical properties.

With the advent of more sophisticated refining techniques, base stocks have been categorized into Group I, Group II and Group III. Group I base stocks is conventionally refined oils. Group II is base stocks that contain greater than 90% saturates and less than .03% sulfur with a VI between 80-119. They are often produced by hydrocracking.

White oils are highly refined petroleum oils that meet food and drug requirements for direct food contact. Customers may ask that the product be certified as USDA H-1 for incidental food contact. While the USDA has disbanded the organization that tested and approved H-1 lubricants for incidental food contact, producers can now self-certify that their products were formally approved under H-1 or currently meet the requirements set forth by that standard.

Synthetic oils are better than petroleum oils for applications running under extreme conditions. They are recommended for applications with very high temperatures or very low temperatures or where service life is extended.

Synthetic oils are classified into several families. Here are a few of the more common ones, and some of their suggested applications.

PAO (Polyalphaolefin*)* molecules are similar to liquid ball bearings. They are made from olefins, which are long molecules with a double bond in the alpha (or first) position. The double bonds in several olefins react together to form a new molecule with the heads coming together in the middle and the rest of the hydrocarbons going outward like the spokes of a wheel. This makes a very round molecule that rolls over itself very easily, giving it excellent lubricity. It is also very stable – very little can attack a round ball – so it has excellent high temperature and oxidation stability. It also doesn't form wax, so it stays fluid down to very cold temperatures.

Synthetic PAO's are used in worm gear applications for energy savings because of their great lubricity. They're also recommended for extremely high and low temperature applications. Their naturally high viscosity index allows the same oil to be used for summer and winter applications.

Alkylated aromatics have excellent solubility for additives. They generally have good low temperature flow characteristics, which make them a good choice for refrigeration applications. They can be used in conjunction with PAO's to enhance solubility and seal compatibility.

Synthetic hydrocarbons, like alkylated aromatics and PAO's, are generally less volatile than petroleum oils. That means that they can be used in engine applications where low viscosity oil is needed for start-up, but the oil cannot evaporate at high engine operating temperatures.

Polyol esters are used for fire resistant hydraulic fluids, refrigeration lubricants compatible with the latest refrigerants such as R-134a, and for jet engine lubricants.

Di-esters have been used for decades as synthetic compressor lubricants because they keep compressor discharge valves clean. Some diesters have excellent biodegradability characteristics and are used as the base for "environmentally friendly" lubricants.

Phosphate esters are used in applications where fire resistance is important. They can be found in aviation hydraulics and in steel mills where a hydraulic hose rupture could cause a fire.

Polyglycols can be used neat, or mixed with water, depending upon the type of glycol. The straight oils are often used in gear applications because of their excellent lubricity. When mixed with water, they are used as fire resistant hydraulic fluids.

Silicone oils are recommended for high temperatures and where petroleum oils may react to process chemicals. They're also recommended for highly oxygenated environments where hydrocarbons can be explosive.

Silicate esters are specialized products used in high-tech areas because of their carefully controlled dielectric properties and wide temperature ranges.

Fluorocarbon oils are extremely inert and expensive. They are recommended for temperatures in excess of 500°F and other specialty applications.

One of the advantages of changing from a mineral to a synthetic is the possibility of extending drain intervals. Other possible benefits include cleaner operation, lower energy consumption, consolidation of lubricants, wider operating range and better heat transfer.

Sometimes, because of price or availability, it is necessary to change from synthetic oil to mineral oil. In this case it is important to consider reduced drain intervals, more deposits, higher energy consumption and narrower operating temperature range.

IT IS IMPORTANT TO CONSULT WITH THE LUBRICANT MANUFACTURER ABOUT CHANGE-OUT PROCEDURES FROM MINERAL

OIL TO SYNTHETIC. Glycols and phosphate esters are not compatible with petroleum lubricants. It is also important to check seal compatibility, particularly if changing from a petroleum product to an ester.

Vegetable based oils – Rapeseed or canola oil is often used as a base for biodegradable hydraulic fluids. Biodegradability can be defined as the ability of a substance to degrade over time to carbon dioxide and water in the presence of water, nutrients and microorganisms. There is no universally accepted test for biodegradability of oils.

Grease is defined as a semi-solid to solid dispersion of a thickening agent in a liquid (base oil.) In simplified terms, it can be described as oil mixed with soap and additives.

What’s the difference between soap and a thickener? Soap is a type of thickener. The process for making soap is called saponification and is achieved by reacting a fatty material with an alkaline material. If your grandmother ever made you wash with homemade lye soap, you’ll remember losing the top layer of your skin along with the dirt. She probably mixed bacon drippings with caustic soda. Sodium soap greases are made almost the same way, although the fat may be tallow or lard rather than bacon drippings. Simple soaps may have dropping points from 250°F to 390°F. Adding a complexing agent raises the dropping point approximately 100°F or more.

There are materials other than soaps that may be used as thickeners, including clay (bentonite or montmorillonite,) polyurea, and silica.

In general, grease is used under the following conditions:

1. Where the machine is so designed that there is no way to retain oil for the parts being lubricated. Examples of this are open gears and many open guide bearings.
2. When the lubricant must act as a seal to prevent the entrance of dirt into a bearing.
   Grease maintains a seal at the ends of the bearing where oil would quickly run out.
3. Where a lubricant is seldom added, as in electric-motor bearings.
4. Where speeds are low and pressures are high. An example would be the roll-neck bearing on the older types of steel mills.

Other advantages of grease over oil include:

Better wear protection at startup. Grease should not leak out of seals so seals can be nonexistent or less expensive. Hand greased components do not require expensive circulating pumps, filters or space-consuming reservoirs. Grease level does not have to be continuously monitored. It is easier to suspend solid fillers such as graphite, molybdenum disulfide and PTFE in grease than in oil.

With all of these advantages, why not use grease for all applications?

Actually, oil is probably the preferred lubricant because it can be circulated to remove heat and contaminants. It can be changed and cleaned, and can be used with smaller bearing clearances. It generally causes less viscous drag and the amount in an application can be more precisely monitored. Whereas oils flow of their own accord, pressure must be applied to most greases to cause them to move or flow.

Be careful when mixing greases with different thickeners. Incompatible grease usually soften but in some cases may harden. The mixture may lower the dropping point or change shear stability. There may be increased oil separation.

Solid lubricants are thin films of a solid interposed between two rubbing surfaces to reduce friction and wear. To be effective, they need low shear strength, low hardness and high adhesion to a substrate material (such as a bearing.) They can be classified as follows:

Inorganic Compounds

Layer-lattice or Laminar Solids – The materials in this class have crystal lattices in layers, Graphite and molybdenum disulfide, popularly known as moly, are examples of this class. Other examples are tungsten disulfide, mica, boron, nitride, borax, silver sulfate, cadmium iodide, and lead iodide.

Miscellaneous Soft Solids – Examples are basic lead carbonate or white lead used in threading compounds, lime used as a carrier in wire drawing, talc and bentonite used as fillers in greases for cable pulling, silver iodide, and lead monoxide.

Chemical Conversion Coatings – These coatings are inorganic compounds developed on the surface of a metal by chemical or electrochemical reaction. Phosphate coats, in particular, are used in the forming and working of metals. The best known films in this class are sulfide, chloride, oxide, phosphate, and oxalate films.

Solid Organic Compounds

Polymer films – Members of the class are polytetrafluoroethylene (or PTFE sold under the brand name Teflon) and polyclorfluoroethylene, both of which give low friction as thin films on metals and excellent wear prevention under conditions of moderate loads and speeds.

Metal films

A thin film of a soft metal on a hard substrate acts as a good lubricant, especially if its adhesion to the substrate metal is good.

Gases

There are applications where gas is used as a lubricant. Some low-friction bearings ride on compressed air, and there are other, more specialized applications that are not covered here.

Friction Control

The primary function of lubricants is to control friction. Friction causes wear, heat, power loss and vibration.

Frictional coefficient is obtained by dividing the force required to move something by its weight. Surprisingly, frictional coefficient of solids is independent of load. But when you think about it, it makes sense. The heavier something is, the more force it takes to push it. The two are proportional to each other.

Friction is not always detrimental. Automatic transmission fluids require certain frictional characteristics in order to shift properly. Lubricated clutches and backstops must retain some friction, otherwise their loads would slip.

Friction is often categorized as static or dynamic. Static friction keeps a body at rest. For example, if a block was resting on an incline, static friction keeps it from sliding. Dynamic friction occurs between two moving surfaces. Once the block began to slide, friction becomes dynamic.

Machinery wear is primarily caused by abrasion, corrosion, and metal-to-metal contact.

Abrasive wear, which is the most common type of wear, is caused by solid particles entering into the area between lubricated surfaces. Abrasive wear usually appears as scratching or scoring of the surface and may be catastrophic. The flushing action of the lubricant, especially in forced-feed or once-through systems, serves to remove potentially harmful solid particles from the area of lubricated surfaces. Seals and filters are important accessories in a lubrication system exposed to abrasive contaminants.

Corrosive wear is generally caused by the products of oxidation of lubricants or the presence of water. Corrosion is the principal cause of wear in internal-combustion engines. Products of combustion are highly acidic and contaminate the lubricating oil.

Lubricants function to minimize corrosive wear in two ways. Proper refinement plus the use of oxidation inhibitors reduces lubricant deterioration, thus keeping the level of corrosive oxidation products low. In addition, corrosive preventatives may be added to protect metal surfaces from those acidic oxidation products that may form. Corrosive products of combustion or other acidic contaminants (such as are encountered in process industries, e.g., paper manufacture) may be neutralized by the use of alkaline additives in the lubricating oil or grease.

Adhesive wear, or wear caused by metal-to-metal contact results from breakdown of the lubricant film. This often occurs at startup before full fluid-film lubrication is established. It can also be the result of excessive surface roughness or interruption of the lubricant supply. Often it is simply the result of a poor choice of lubricants.

This type of wear is usually severe. A plentiful supply of the proper viscosity of oil is often the best way to avoid this condition. In boundary lubrication wear from metal-to-metal contact is minimized by the proper chemical additives.

Erosion wear is the removal of material from surfaces due to momentum effects. Just like a river erodes the side of a mountain, fast flowing particles can erode metal surfaces.

Fatigue wear occurs with repeated bending stresses and usually occurs in rolling element bearings which experience EHL lubrication.

The chain reaction of abrasive wear occurs when:

Abrasive particles become work hardened

Work hardened particles produce more abraded particles

New particles become work hardened

The **chain continues** until the particles are removed by filtration or the equipment fails.

Five Rights of Lubrication

Proper lubrication consists of choosing the **right type**, **right quality** the **right amount** at the **right place** at the **right time**

Consider the design of a machine and its operating conditions when selecting the proper lubricant. Here are some questions to ask:

Is the machine designed for oil or grease? Look for oil reservoirs or grease fittings.
Is the lubricant applied manually or through a centralized system?
What part is being lubricated, bearing, gear, piston, hydraulic system, compressor?
What are its speeds and loads? Does it operate at slow speed and heavy load, at high speed and light load, or at some intermediate combination of speed and load?
Are the bearings plain or anti-friction?
What is the ambient temperature? Is the machinery indoors or outdoors?
What is the operating temperature?
What contaminants may be able to enter or contact the lubricant?
How long is the lubricant expected to remain in the machine?

What lubricant is recommended in the maintenance manual?
What is the telephone number of the machine manufacturer in case there are any questions?
Are there any paints, elastomers or seals that might be affected by exposure to synthetic oil?
Does the application call for a specialized lubricant, such as food grade, fire resistant, or biodegradable?
What lubricant is already in the application? Can it be flushed out, or are there samples available for compatibility testing?

Oil Recommendations

The principal properties of lubricating oils are:

Viscosity
Additives
Base oil type

Viscosity of oil is critical, especially if the application is running at temperature or speed extremes. Choose oil with a high viscosity at room temperature if you know it is going into a high temperature application because it has to be thick enough to separate moving parts as the oil heats up. If you know that the oil will be used to start up machinery in Alaska, choose oil with a low viscosity at room temperature. The oil must be thin enough to flow at sub-zero temperatures.

In general, high viscosity oils are used at slow speeds under high pressure, since the heavy oil better resists being squeezed out from between the rubbing parts. Light oils are used at higher speeds and lower pressures because they do not impose as much drag.

One method of choosing the right viscosity is to find the dN or dmN of a rolling contact bearing. The **dN is the speed of the bearing times it's inside diameter in mm. dmN is the speed of the bearing times its pitch diameter in mm, which is the outside diameter plus the inside diameter divided by two.** It is more accurate because it takes into account the shape of the bearing. There are charts that show the proper value for different dN or dmN values relating to the viscosity in cSt at the operating temperature of the bearing.

Additives affect lubricity, viscosity, viscosity index, detergency, dispersancy, demulsibility, antiwear properties, extreme pressure performance, pour point , rust inhibition, oxidation inhibition, foam characteristics, tackiness, and many other fluid properties.

Additives, base oil type (i.e. petroleum, vegetable, synthetic) and solid fillers can also influence your recommendation for the proper grease for the job. The following is a chart that shows the typical additive profile of common industrial and transportation lubricants.

Additive	Turbine	Gear	Hydraulic	Engine	Paper Machine	Circulating
Rust Inhibitor	✓	✓	✓	✓	✓	✓
Oxidation Inhibitor	✓	✓	✓	✓	✓	✓
Extreme Pressure		✓			(4)	
Antiwear	(1)		✓	✓	(5)	
Detergents				✓	✓	
Dispersants		(2)		✓		
Antifoam	✓	✓	✓	✓	✓	✓
V. I. Improver			(3)	✓		
Demulsifiers	✓	✓	✓		✓	✓

(1) Some geared turbines require ashless antiwear package.
(2) Gear oils may contain small amounts of dispersant.
(3) Hydraulic oils operating in low temperature environment may contain a V. I. Improver.
(4) Some paper machine oils contain a non-aggressive antiwear/EP package.
(5) Paper machine oils may contain antiwear such as ZDDP

Base oil type, as discussed above, can have a significant effect on pour point, oxidation stability, thermal stability, viscosity index and other properties.

Grease Recommendations

When making a grease recommendation, first consider:

Thickener type
Base oil viscosity
Consistency

The **thickener** is important because it imparts qualities to the grease beyond just its consistency. For example, if you had an application where water was washing over a bearing, you would not choose sodium soap grease, yet you might pick it if the conditions were simply humid.

Here are some other examples of applications that are dependent on thickener type:

High speeds – use a channeling type thickener to reduce drag
High temperatures – choose polyurea, a complex soap, fluorinated grease or silicone
High exposure to water – Calcium greases, complex soaps, polyurea
High humidity – sodium soaps

Base oil viscosity is influential under high- and low-speed applications and also high- and low-temperature applications. As in the case of lubricating oils, the low viscosity oils are recommended for high speeds and low temperatures. High viscosity oils are used for low speeds, high loads and high temperatures.

The consistency of the grease can be critical, particularly if it is to be pumped through a centralized system. Most automatic lubricators require an NLGI 1 or 0 grade grease.

Moving parts of machine

Lubrication is necessary at all points at which one surface rubs against another. This occurs in bearings, in gears, and between pistons and the cylinders in which they operate. A machine may be very large and quite complex in its design, but it can generally be broken down into these three components. Lubricated parts that are not covered in this section include, but are not limited to, springs, shock absorbers, valves and diaphragms. Bearings and gears are discussed in separate sections, but here are a few words on piston lubrication.

Pistons generally slide up and down or back and forth in a cylinder. The automobile engine is a good example. Combustion of fuel in the space above the piston drives it down causing the crankshaft to turn. Many pumps and air compressors use pistons to move gas or fluids.

Since it is necessary to lubricate rubbing surfaces, it is apparent that a film of oil must be provided between the piston and the cylinder. Pistons generally have rings that sit in annular grooves.
Oil not only lubricates the piston rings but also helps to make them seal more perfectly. It is important to choose oil with high enough viscosity at operating temperature to provide a good seal.

In internal combustion engines, the lubricant must contain detergents and dispersants to counteract the effects of combustion gases. In air compressors, it must have high thermal and oxidation stability to perform at high gas discharge temperatures. The choice of base oils and additives can contribute to good piston lubrication.

The only boundary lubrication regime that occurs in a piston is at top dead center or when the slide of the piston reverses.