Facilities Instructions, Standards, and Techniques – Volume 2-4

Lubrication of Equipment

U.S. Department of the Interior

May 2024

Cover Photo
Bureau of Reclamation, Typical generator bearing.

(FIST 025) 07/01/2004
NEW RELEASE
(Minor revisions approved 05/29/2024)

Facilities Instructions, Standards, and Techniques – Volume 2-4

Lubrication of Equipment

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and
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Bureau of Reclamation
Power Resources Office
Denver, Colorado

May 2024

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acronyms and Abbreviations

AGMA	American Gear Manufacturers' Association
ASTM	American Society for Testing and Materials
CEATI	Centre for Energy Advancement through Technological Innovation
EA	environmentally acceptable
EAL	environmentally acceptable lubricant
FIST	Facilities Instructions, Standards, and Techniques
HPLIG	Hydraulic Plant Life Interest Group
ISO	International Organization for Standardization
NLGI	National Lubricating Grease Institute
PRO	Power Resources Office
psi	pounds per square inch
RPVOT	Rotating Pressure Vessel Oxidation Test
Reclamation	Bureau of Reclamation
SDS	Safety Data Sheet
TSC	Technical Service Center
ZDDP	zinc dialkyl dithiophosphates

Symbols

β_2	Beta rating
=	equals
%	percent

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1.0 Introduction

The Bureau of Reclamation operates and maintains hydroelectric powerplants, switchyards, pumping plants, water delivery equipment and associated facilities in the 17 western United States. These facilities house complex electrical and mechanical equipment that must be kept operational because they are critical to the electric power and water delivery systems relied on by many. FIST are technical documents that provide criteria and procedures that should be utilized by the offices involved in managing Reclamation facilities and assets.

This document establishes standard technical practices to ensure the, safe, reliable, economic and efficient O&M of Federal facilities by keeping related assets in good condition and ultimately protecting Federal investments. These technical practices provide a sufficient level of detail to ensure consistent application while providing flexibility for the use of innovative techniques and approaches. This document was developed with input from staff in Reclamation's Denver, regional, and area offices.

1.1 Purpose and Scope

This document is intended to promote uniformity in the manner that assets are managed, documented, and coordinated, and may be utilized by transferred facilities and other entities as appropriate. It establishes consistent procedures, minimum standards and O&M criteria for hydroelectric equipment and systems owned and operated by Reclamation. Other technical documents may provide additional electrical and mechanical maintenance information for the equipment or systems discussed in this document.

O&M requirements are based on industry standards and experience. Maintenance requirements vary based on equipment condition and past performance, and sound engineering practices and maintenance management should be employed for special circumstances. Manufacturer recommendations and instructions should be consulted for additional maintenance that may be required beyond what is stated in this manual.

This volume includes standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of mechanical equipment in Reclamation facilities.

1.2 Reclamation Standard Practices

FIST manuals are designed to provide guidance for maintenance and testing on equipment in Reclamation's facilities. There may be multiple ways to accomplish tasks outlined in this document. Facilities may exercise discretion as to how to accomplish certain tasks based on equipment configurations and available resources.

Reclamation's regions, PRO, and TSC agree that certain practices are required to be consistent across all Reclamation facilities. Mandatory FIST procedures, practices, and schedules that appear in **{Red, bold, and bracketed}** or **[Black, bold, and bracketed]** text are considered Reclamation requirements for the O&M of equipment in power facilities. RM D&S FAC 04-14, *Power Facilities Technical Documents*, describes the responsibilities required by text designations: **{Red, bold, and bracketed}**, **[Black, bold, and bracketed]**, and plain text, within this technical document.

Refer to RM D&S FAC 04-14 for more details concerning technical documents.

1.3 FIST Revision Requests

The FIST Revision Request Form (POM-226) is used to request changes to a FIST document. The request will include a summary of the recommended changes and a basis for the revision or new FIST. These forms will be submitted to the Manager, PRO. The PRO Manager will keep a list of Revision Requests for each FIST and include these in the next scheduled revision unless the change is prioritized sooner.

2.0 Fundamentals of Lubrication

The proper selection and use of lubricants, as well as the care and operation of lubricating systems, is an essential part of any powerplant maintenance program. Any piece of equipment with moving parts depends on some type of lubricant to reduce friction and wear and to extend its life. To choose an appropriate lubricant for a particular application and to maintain the lubricant's effectiveness, a basic understanding of lubrication theory and the characteristics of lubricants can be very beneficial. This document discusses lubrication fundamentals, lubricant characteristics, additives, maintenance of lubrication systems, and the selection of lubricants for common powerplant equipment.

The basic purpose of a lubricant is to reduce friction and wear between two surfaces moving relative to one another. In most cases, a lubricant also dissipates heat, prevents rust or corrosion, acts as a seal to outside contaminants, and flushes contaminants away from bearing surfaces. For the lubricant to accomplish these functions, a fluid lubricant film must be maintained between the moving surfaces. This condition is known as fluid film lubrication.

2.1 Fluid Film Lubrication

Fluid film lubrication reduces friction between moving surfaces by substituting fluid friction for mechanical friction. Fluid film lubrication is illustrated on Figure 1. Surface 1 moves over surface 2 at velocity V, separated by a film of fluid with a thickness h. The oil film can be considered to be made up of many layers. The layer in contact with moving surface 1 clings to that surface and moves at the same velocity. Similarly, the layer in contact with surface 2 is stationary. The remaining inner layers move at velocities directly proportional to their distance from the moving surface. For example, at a distance of ½ h from surface 1, the velocity would be ½ V. The force, F, required to move surface 1 across surface 2 is the force required to overcome the friction between the layers of fluid. This internal friction, or resistance to flow, is defined as the viscosity of the fluid. Viscosity is discussed in more detail later in this document.

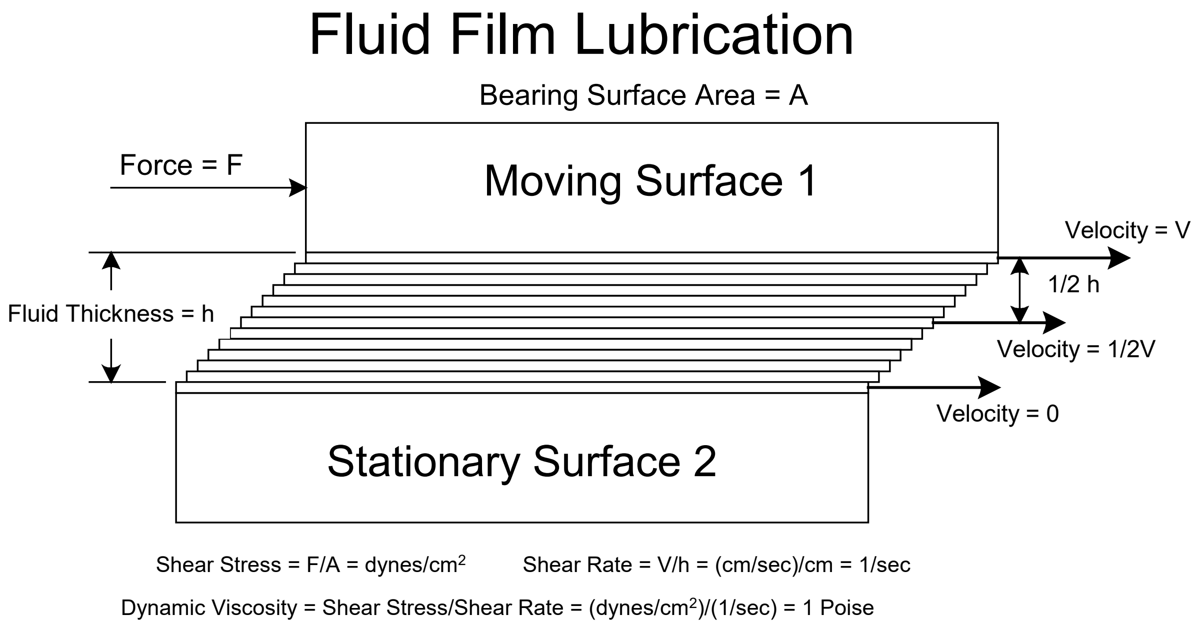

Figure 1.—Fluid film lubrication.

To keep the surfaces separated, the fluid pressure must be high enough to support the load. In highly loaded bearings, such as thrust bearings and horizontal journal bearings, relatively high fluid pressures are necessary. If this pressure is supplied by an outside source, it is called hydrostatic lubrication. If the pressure is generated internally (i.e., within the bearing by dynamic action), it is referred to as hydrodynamic lubrication. In hydrodynamic lubrication, a fluid wedge is formed by the relative surface motion of the bearing journals or the thrust runners over their respective bearing surfaces. This wedge is similar to the fluid wedge that forms under a speeding boat, pushing the bow out of the water, or under water skis, allowing the skier to skim across the water.

Figure 2 illustrates the wedge action in a pivoting shoe thrust bearing. As the thrust runner moves over the thrust shoe, fluid adhering to the runner is drawn in between the runner and the shoe, causing the shoe to pivot and forming a wedge of oil. As the speed of the runner increases, the pressure of this wedge increases, the runner is lifted vertically, and full fluid film lubrication takes place.

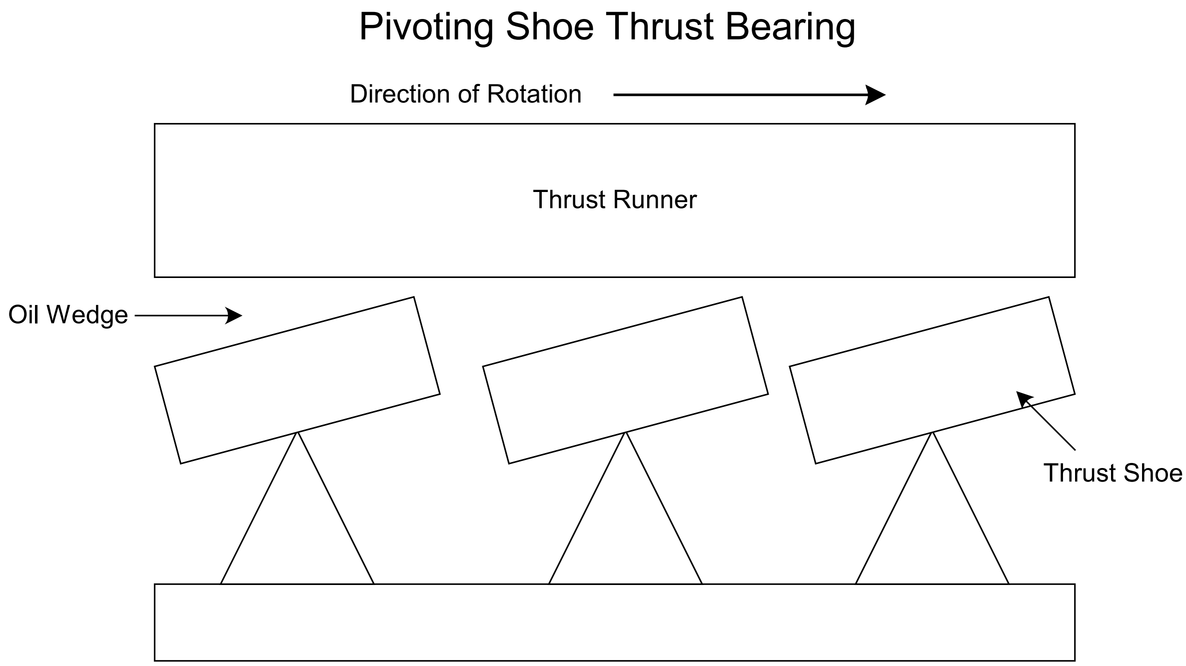

Figure 2.—Pivoting shoe thrust bearing.

Figure 3 demonstrates the wedge that forms in a horizontal journal bearing. In drawing "A," the journal is at rest and the weight of the journal has squeezed out the oil film at "E" so that the journal rests on the bearing surface. As rotation starts, as shown in drawing "B," the journal has a tendency to roll up the side of the bearing. At the same time, fluid adhering to the journal is drawn into the contact area at "F." As the speed increases, an oil wedge is formed at "G." The pressure of the oil wedge increases until the journal is lifted off the bearing at "H," as shown in drawing "C." Drawing "D" shows the condition at full speed. The journal is not only lifted vertically but is also pushed to the left by the pressure of the oil wedge so that the resultant force from the fluid pressure acts along the line "PO." The minimum fluid film thickness at full speed occurs at "J", not at the bottom of the bearing.

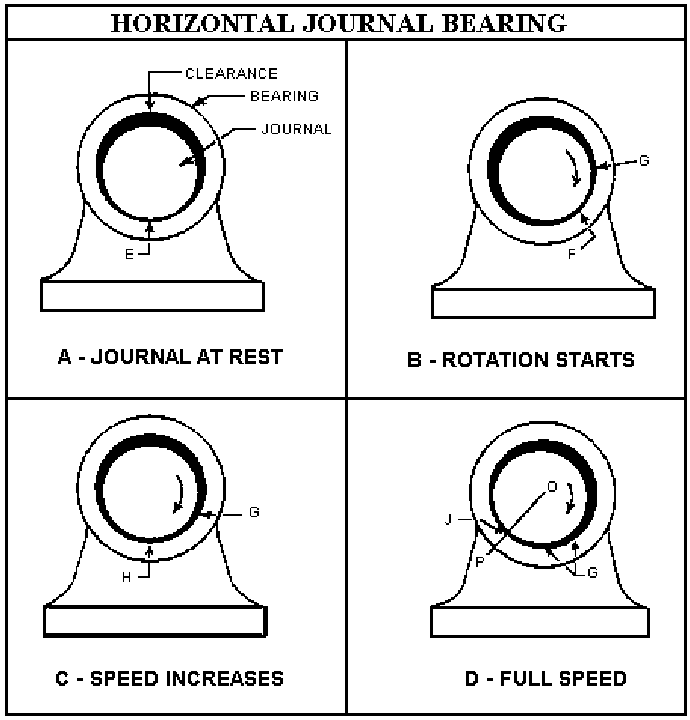

Figure 3.—Horizontal journal bearing
(courtesy of Conoco Inc.)

In both the pivoting shoe thrust bearing and the horizontal journal bearing, the minimum thickness of the fluid film increases with an increase in fluid viscosity and surface speed and decreases with an increase in load.

2.2 Boundary Lubrication

A well-designed fluid film bearing operates with a full fluid film under most circumstances. Under less-than-ideal conditions, such as during start up and shut down, the fluid film may become so thin that contact may occur between the rubbing surfaces. This condition is called boundary lubrication and is compared to fluid film lubrication in Figure 4. Observing the bearing surfaces at a microscopic level reveals peaks on the surfaces, referred to as asperities. During boundary lubrication conditions (i.e., low velocities), the asperities of one surface contact the other surface and can be torn or worn off. The lubricant’s viscosity alone cannot provide sufficient lubrication under these circumstances. To combat this, use lubricant additives that form an extremely thin boundary film on the bearing surfaces or, in the case of hydroelectric generator thrust bearings, use an outside pressure source or hydrostatic system.

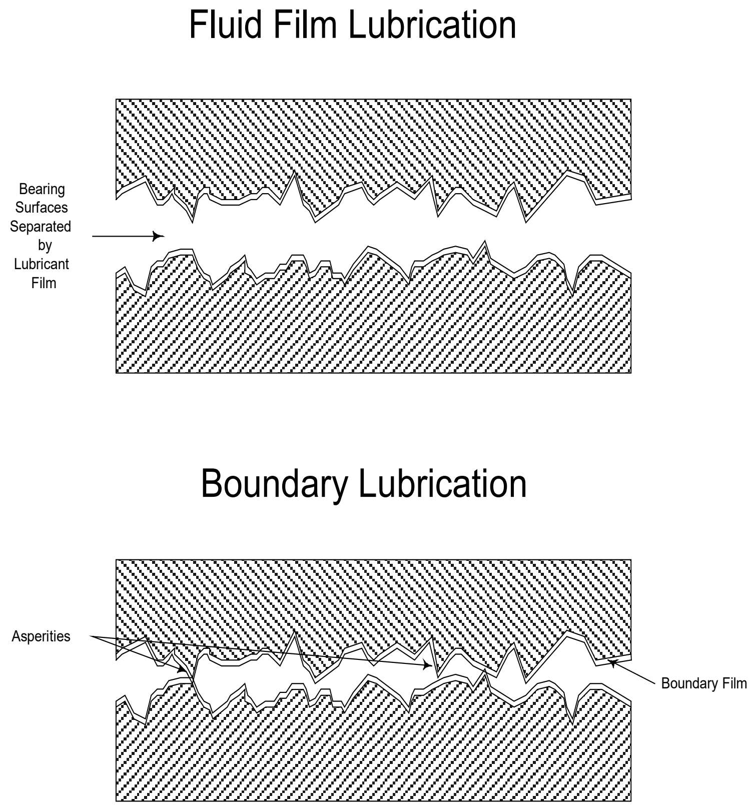

Figure 4.—Fluid film and boundary lubrication.

Some reciprocating equipment, such as pistons in compressors or engines, and slow-moving equipment, such as turbine wicket gates, rely entirely on boundary lubrication. Gear teeth also depend on boundary lubrication. For boundary lubrication to be effective (i.e., to reduce friction and provide damage control to the rubbing surfaces), a very thin film of lubricant and/or additive must be maintained. This can be accomplished through the use of various extreme pressure, antiwear, and lubricity additives. Solid lubricants, such as graphite, molybdenum disulfide, and polytetrafluoroethylene (PTFE) may also be added by the lubricant manufacturer, but research on greases used in boundary lubrication applications following the Folsom gate failure found that adding molybdenum disulfide or PTFE was not effective.

3.0 Lubricant Characteristics

3.1 Oil

3.1.1 General

A lubricating oil is composed of a base stock blended with various additives to enhance performance and maintain quality. The base stock may be a mineral (petroleum), vegetable, or a synthetic oil. Petroleum oils are usually classified as either paraffinic or naphthenic. Paraffinic oils, as the name implies, contain paraffin wax and are the most widely used type of lubricating oil base stock. In comparison to naphthenic (low wax content), paraffinic oils are more resistant to oxidation, have a lower volatility, a higher viscosity index, and are generally a better lubricant. Since naphthenic oils are essentially wax free, they have naturally low pour points. Mineral oils are the most common base oils.

Vegetables oils are derived from vegetables, biodegradable, and considered less toxic than petroleum-based lubricants. These oils typically require additives to increase their low oxidation stability. Without additives, they can oxidize quickly and become rancid. Vegetable oils can be expensive because of increased manufacturing effort due to the formulation of additives, chemical modification of the vegetable oil, and special refining processes depending on the type of seed.

Synthetic oils are man-made fluids synthesized from different chemical compounds. Group IV base oils are polyalphaolefins (PAOs), and Group V base oils include diesters/polyol esters and polyalkylene glycols (PAGs). Synthetic based lubricants are produced to provide a product with precise and predictable properties through the chemical reaction of materials of a specific chemical composition. Synthetic lubricants are superior to petroleum lubricants in most circumstances. Despite the superior performance of synthetic lubricants, their use is usually limited to severe or unusual applications because of their cost, which can be many times higher than a similar petroleum product.

No matter the oil base, the manufacturer should provide specific information on their lubricant type and on the periodic recommended maintenance for a particular application.

3.1.2 Oil Characteristics

3.1.2.1 Viscosity

One of the most important characteristics of a lubricant is its viscosity. As mentioned earlier, viscosity is a measure of a fluid’s internal friction or resistance to flow. The higher the viscosity of a fluid, the greater the internal resistance and the greater its load capacity. However, higher internal resistance can cause temperatures to rise. The correct viscosity for any particular application is thick enough to support the load but not so thick as to cause excessive fluid friction and the corresponding increase in temperature.

Dynamic or absolute viscosity is defined as the ratio of shear stress to shear rate and is most commonly measured in poise or centipoise. Figure 1 illustrates this. Kinematic viscosity is the dynamic viscosity divided by the density of the lubricant and is most commonly measured in centistokes. The kinematic viscosity is related to the time required for a fixed volume of lubricant to flow through a capillary tube at a given test temperature, usually 40 degrees Celsius (ºC) or 100ºC, under the influence of gravity. The kinematic viscosity is the most common method of expressing a lubricant's viscosity.

There are many other methods for measuring and expressing the viscosity of lubricants. A common but outdated viscosity measuring system seen in many original powerplant equipment specifications is Saybolt Universal Seconds (SUS), or Saybolt Seconds Universal (SSU). In this system, the viscosity is the amount of time, in seconds, it takes for 60 cubic centimeters of the lubricant to flow through a standard orifice at a given test temperature, usually 100 degrees Fahrenheit (ºF) or 210ºF.

Various organizations have developed grading systems for lubricant viscosity. The most common grading systems now in use have been developed by the International Organization for Standardization (ISO), the Society of Automotive Engineers (SAE), and the American Gear Manufacturers' Association (AGMA). Note that these grades do not correspond to a specific kinematic or Saybolt viscosity value, but to a viscosity range. Figure 5 compares these viscosity grading systems to kinematic and Saybolt viscosities.

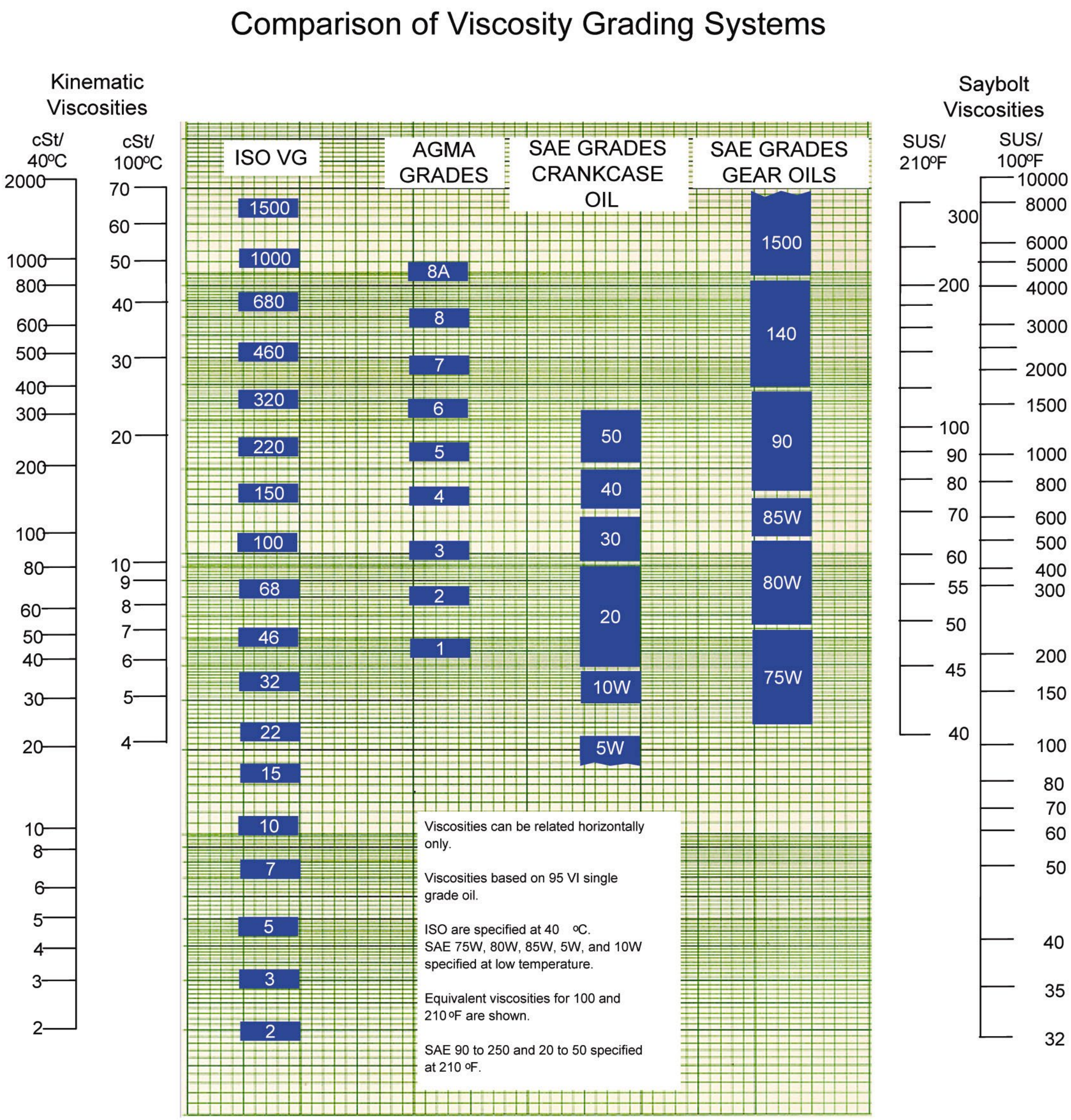

Figure 5.—Viscosity grading systems comparison.

3.1.2.2 Viscosity Index

An oil's viscosity index (VI) is an empirical number used to describe its viscosity-temperature relationship. A high VI for an oil indicates a relatively low change in viscosity for a change in temperature.

3.1.2.3 Pour Point

A fluid's pour point is the lowest temperature at which the fluid will flow. In paraffinic oils, the pour point is the result of the crystallization of waxy particles. In naphthenic oils, the pour point is the result of the decrease in viscosity caused by a decrease in temperature. This property is important in choosing a lubricant for cold weather applications.

3.1.2.4 Flash Point

The flash point is the lowest temperature at which vapors are given off in sufficient quantity to ignite when brought into contact with a spark or flame. The flash point is not necessarily the safe upper temperature limit. Instead, it is a relative indication of the fire and explosion hazard of a particular oil. The flash point can also be used as an indication of the evaporation losses that can be expected under high temperature applications.

3.1.2.5 Fire Point

The fire point is the lowest temperature at which vapors are given off in sufficient quantity to sustain combustion.

3.1.2.6 Neutralization Number

The neutralization number is a measure of the acidity of an oil. Specifically, it is the amount, in milligrams, of potassium hydroxide (KOH) required to neutralize 1 gram of oil. A relative increase in the neutralization number indicates oxidation of the oil.

3.2 Grease

3.2.1 General

Lubricating grease is a mixture of a lubricating fluid, a thickening agent, and additives. Petroleum oils mixed with a soap thickening agent make up most of the grease in use today. The soaps are formed by the reaction of animal or vegetable fats or fatty acids with strong alkalis such as calcium or sodium. Non-soap thickening agents, such as modified clays and polyureas, are also used in some instances. Table 1 lists some of the thickening agent types and their usual characteristics. Synthetic oils are used in severe conditions or when a normal petroleum oil is not adequate.

Table 1.—Grease application guide

(Copyright 1989, National Grease Lubricating Institute, reprinted with permission)

Grease Application Guide										
Properties	**Aluminum**	**Sodium**	**Calcium Conventional**	**Calcium Anhydrous**	**Lithium**	**Aluminum Complex**	**Calcium Complex**	**Lithium Complex**	**Polyurea**	**Organo-Clay**
Dropping Point ºC	110	163-177	96-104	135-143	177-204	260+	260+	260+	243	260+
Max. Usable Temp ºC	79	121	93	110	135	177	177	177	177	177
Water Resistance	Good to Excellent	Poor to Fair	Good to Excellent	Excellent	Good	Good to Excellent	Fair to Excellent	Good to Excellent	Good to Excellent	Fair to Excellent
Work Stability	Poor	Fair	Fair to Good	Good to Excellent	Good to Excellent	Good to Excellent	Fair to Excellent	Good to Excellent	Poor to Good	Fair to Good
Oxidation Stability	Excellent	Poor to Good	Poor to Excellent	Fair to Excellent	Fair to Excellent	Fair to Excellent	Poor to Good	Fair to Excellent	Good to Excellent	Good
Protection Against Rust	Good to Excellent	Good to Excellent	Poor to Excellent	Poor to Excellent	Poor to Excellent	Good to Excellent	Fair to Excellent	Fair to Excellent	Fair to Excellent	Poor to Excellent
Pumpability	Poor	Poor to Fair	Good to Excellent	Fair to Excellent	Fair to Excellent	Fair to Good	Poor to Fair	Good to Excellent	Good to Excellent	Good
Oil Separation	Good	Fair to Good	Poor to Good	Good	Good to Excellent	Good to Excellent	Good to Excellent	Good to Excellent	Good to Excellent	Good to Excellent
Appearance	Smooth and Clear	Smooth to Fibrous	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery	Smooth and Buttery
Other Properties		Adhesive and Cohesive	EP Grades Available	EP Grades Available	EP Grades Available, Reversible	EP Grades Available, Reversible	EP and Antiwear Inherent	EP Grades Available	EP Grades Available	
Principal Uses	Thread Lubricant	Rolling Contact Bearings	General Uses for Economy	Military Multiservice	Multiservice Automotive & Industrial	Multiservice Industrial	Multiservice Automotive & Industrial	Multiservice Automotive & Industrial	Multiservice Automotive & Industrial	High Temp. (Freq. Relube)

The lubricating fluid, which is usually petroleum oil, is the main ingredient of all greases, making up 85 to 95 percent of the final product. While thickening agents impart some important characteristics to a grease, the oil and its additives perform the actual lubrication. The base oil's characteristics, such as viscosity and pour point, influence the performance of the grease.

As moving parts come in contact with the grease, oil "bleeds" from the grease to provide either fluid film or boundary lubrication. The oil picked up by the moving parts will be lost because of evaporation or leakage, so the grease must continually "bleed" to provide sufficient lubrication. Eventually, the grease must be replenished or replaced.

Grease is used when it is not practical or convenient to use oil. In applications where oil would leak out of the bearing or where the bearing is submerged in water, grease works very well. Grease also has the advantages of requiring less frequent relubrication or replenishment than many oil lubricated systems and can more readily seal dust and dirt out of the bearing.

3.2.2 Grease Characteristics

3.2.2.1 Consistency

The consistency, or hardness, of a grease is the measure of its resistance to deformation by an applied force and is, in most cases, the most important characteristic of a grease. A grease's consistency depends on its base oil's viscosity and the type and amount of thickening agent used. Consistency is measured in terms of the depth, in tenths of a millimeter, that a standard cone will sink into a grease under prescribed conditions and is referred to as the penetration number. The National Lubricating Grease Institute (NLGI) has established consistency numbers, or grades, ranging from 000 (soft) to 6 (hard), corresponding to specified ranges of penetration numbers. This rating system covers most greases, but there are greases available that are softer than a NLGI No. 000 or harder than a No. 6.

The consistency of a grease should be soft enough to allow easy application and provide acceptable lubrication but not so soft that the grease leaks out of the area being lubricated. In centralized greasing systems, a grease with a consistency softer than is optimum for the lubrication of equipment may be required in order to be pumped through long lines and metering valves. The consistency must be thin enough to be pumped through the grease lines but thick enough to stay in the bearings once it is there. A grease that is impervious to water and has excellent lubricating qualities is useless if it doesn't get to the component. Some compromise in the desired qualities is required to obtain a workable grease. As with an oil's viscosity, grease consistency becomes thinner, or more fluid, with an increase in temperature and thicker, or more solid, with a decrease in temperature.

3.2.2.2 Consistency Stability.

The consistency of a grease may change while in use primarily because of the mechanical shearing of the thickening agent particles. The resistance to this change is referred to as consistency stability.

3.2.2.3 Dropping Point

The dropping point of a grease is the temperature at which the grease becomes soft enough for a drop of fluid to fall from the grease. A grease acts as a fluid at or above its dropping point. Note that the dropping point is not the highest allowable operating temperature for a grease, as the grease may actually start to break down far below the dropping point. The dropping point should only be used as a general indication of a grease's temperature limit. Most grease manufacturers list a usable temperature range along with the dropping point in the specifications for a grease.

The consistency of most greases permanently changes if exposed to temperatures at or above their dropping point, but a few types of grease have the ability to return to their original consistency. This property is referred to as reversibility.

4.0 Lubricant Additives

While it is beneficial to have as few types of oil in stock as possible, there is no one all-purpose oil that can be used in all applications. Practically all lubricants contain additives to enhance existing properties or to impart new properties. Various additives, such as emulsifiers, rust and corrosion inhibitors, detergent, and dispersants are added to oil to enhance performance for a given application. Characteristics that may be desirable in one case may be very undesirable in another. For example, emulsifiers are added to motor oil to allow the oil to hold water in an emulsion until the engine's heat can boil it away. In bearing lubrication, where there is not sufficient heat to evaporate the water, the oil must be capable of readily separating from water.

Three general classifications of lubricant additives are surface protective, performance enhancing, and lubricant protective. As the names imply, surface protective additives protect the bearing surfaces, performance enhancing additives enhance the lubricant's performance for particular applications, and lubricant protective additives prevent deterioration of the lubricant.

4.1 Surface Protective Additives

4.1.1 Lubricity Additives

Lubricity, also referred to as oiliness, with respect to lubricating oil, is defined as the ability of an oil to reduce friction between moving surfaces. Lubricity additives, usually vegetable or animal fats, enhance lubricity by tenaciously adhering to the metal's surface, forming an adsorbed film of high lubricating value.

4.1.2 Antiwear Additives

Antiwear additives work by coating a metal's surface. If light metal-to-metal contact is made, the heat from the friction melts the additives, forming a liquid layer between the surfaces. This molten additive layer, being softer than the metal, acts as a lubricant, preventing wear of the metal surfaces.

4.1.3 Extreme Pressure Additives

Extreme pressure (EP) additives work by reacting with a metal to form a compound that acts as a protective layer on the metal's surface. Because this layer is softer than the metal itself, under extreme pressure conditions, the compound layer wears away first, protecting the metal. As this layer is removed, the EP additive acts to form another layer. In contrast to the action of antiwear additives, EP additives control wear instead of preventing it. Some EP additives, because of their reactive nature, can be corrosive to brass or copper-containing alloys. To prevent excessive corrosion, most EP additives are activated by the heat of friction created during extreme pressure conditions but do not react at room temperature.

4.1.4 Tackiness Agents

Tackiness agents act to increase the adhesiveness of an oil or grease.

4.1.5 Corrosion and Rust Inhibitors

Rust inhibitors protect ferrous (iron or steel) parts by forming a film on the part, thus resisting attack by water. Corrosion inhibitors act in a similar way to protect nonferrous parts and also act to neutralize acids with a basic compound such as calcium carbonate.

4.1.6 Detergents and Dispersants

Detergents and dispersants are used primarily in engine oils to keep surfaces free of deposits and keep contaminants dispersed in the lubricant.

4.2 Performance Enhancing Additives

4.2.1 Viscosity Index Improvers

Viscosity index improvers lower the rate of change of viscosity with temperature and are used to produce multigrade motor oils.

4.2.2 Pour Point Depressants

Pour point depressants enable lubricants to flow at low temperature.

4.2.3 Demulsifiers

A demulsifier promotes the separation of oil and water in lubricants exposed to water.

4.2.4 Emulsifiers

An emulsifier promotes the rapid mixing of oil and water to form a stable emulsion. Emulsifiers are used in motor oils to allow water, formed by combustion of fuel, to be kept in emulsion until engine heat can evaporate it. Emulsifiers are also used in soluble oils used in some metal working operations and in fire-resistant hydraulic fluids. Emulsification is usually not a desirable property in most hydraulic fluids or turbine oils.

4.3 Lubricant Protective Additives

4.3.1 Oxidation Inhibitors

Oxidation inhibitors, or antioxidants, lengthen a lubricant's service or storage life by increasing its oxidation resistance by binding the free oxygen in the oil or by neutralizing the catalytic effect of metals.

4.3.2 Foam Inhibitors

Foam inhibitors prevent lubricant foaming by decreasing the surface tension of air bubbles, allowing them to combine into large ones, which break more rapidly.

4.4 Additive Depletion

Some additives, such as antiwear and extreme pressure additives, and some inhibitors such as rust, oxidation, and corrosion inhibitors, are consumed as they are used. When all of a particular additive has been consumed, the lubricant is no longer capable of performing as originally intended. Usually, this condition requires replacement of the lubricant, but in some cases, replenishment of the additive is possible. Consult the lubricant manufacturer before attempting this.

4.5 Aftermarket Additives

A number of aftermarket lubricant additives are marketed as solutions to many lubricating problems. These additives may contain Teflon ® or some other "secret ingredient" that supposedly imparts improved lubricating qualities to the lubricant. There may be cases where these additives improve performance in some way, or at least appear to improve performance, but in most cases their usefulness is questionable at best. These additives may actually reduce a lubricant's effectiveness by reacting with some of the additives already in the oil.

The major lubricant manufacturers spend a great deal of time and money formulating their products to provide optimum performance for particular applications. If some additive is available that will improve a lubricant to the extent claimed by many of the aftermarket additive distributors, most lubricant manufacturers would have added it to their product.

If a lubricant is not performing as it should, a different lubricant may be required, or some mechanical problem may exist. Consult the lubricant's manufacturer before adding anything to a lubricant. The lubricant manufacturer can provide information on the possible benefits or consequences of the additive and determine whether a different lubricant is required.

5.0 Maintenance of Lubrication Systems

Oil lubrication can take many forms, ranging from a simple squirt oil can to a complex circulating system. Regardless of application method, the intent for all these forms is the same—to keep a lubricant film between moving surfaces. For a lubricant to perform as intended, some maintenance of the system is required. Take care to ensure that the correct quantity and type of lubricant is used, and that the lubricant and the system are clean and free of contaminants. Cleanliness is extremely important. All seals in a system should be installed properly and in good condition. Dirt, water, or other contaminants can not only cause premature wear of the bearings and hydraulic system components, but they can also deplete some of the oil's additives.

5.1 Oil Lubricated Systems

5.1.1 Oil Testing and Analysis

The periodic analysis of lubricating oil can be a beneficial part of a preventive maintenance program. Tests can measure the effects of oxidation and detect the types and amount of various contaminants in the oil. These can be helpful in detecting problems within a lubricating system, determining whether the oil is still serviceable, and setting up a filtering or purification schedule. Keeping track of the condition of the oil can prevent damage to equipment caused by oil deterioration. A variety of tests can be performed on an oil depending on its type and service. Some tests can be performed in the field to obtain a quick indication of an oil's condition, but because field testing is not as complete or as accurate as laboratory analysis, laboratory tests should be performed as well.

5.1.1.1 Sample Collection

For oil analysis to be effective, the sample must be representative of the oil in the system. A sample skimmed off the top of an oil tub after the oil has cooled and contaminants have settled out, may test cleaner than the oil actually is. Conversely, a sample taken from a drain line at the bottom of an oil tub will likely contain sediment and contaminants that have built up over time, providing a much worse picture of the oil condition. Ideally, the oil sample should be drawn from the middle of the oil tub while the unit is operating. In most cases this is not practical and other procedures are required. The procedure used varies depending on whether the system is circulating.

Circulating systems have a continuous flow of oil provided by a pump. An example of this in a hydroplant is a turbine guide bearing where the oil is supplied through the side of the bearing and flows out the top and bottom of the bearing to return to the sump. In a circulating system, it is best to obtain a sample from the supply pipe to the bearing. The sampling port should be from an area where there is turbulence in the pipe, such as at or directly after an elbow or other fitting. This ensures that the oil is well mixed. The sampling port should be downstream from the pump but before any inline filters.

The most common noncirculating systems in hydroelectric plants are the generator guide and thrust bearing. Gear boxes, as found on gate operators, are another example. The bearings or gears are submerged or partially submerged in a tub of oil with no external pump to circulate the oil. Also, thrust bearings typically have hydrostatic lubrication through the high-pressure lubrication system, but these are operated only during startup and shutdown. When the unit is operating, oil in the tub circulates because of the rotating shaft. Once the unit is shut down, any contaminants will separate out of the oil. To get a representative sample of the oil, take the sample while the unit is operating or shortly after shutdown. The most common place to take a sample on a noncirculating system is from the drain. Even with the unit running, a sample drawn from the drain will likely have a higher concentration of contaminants than the oil lubricating the bearing. If this is the only place to obtain a sample, it is best to wait until the unit is shut down and the bearing is being drained for filtering. Drain the bearing while the oil is still warm. To flush the line and sediment that may be near the drain, drain at least ¼ of the oil out of the tub before taking the sample.

If the sampling is to be accomplished on a regular basis between filtering, use a permanently mounted tube extending into the bearing housing. The tubing can be installed on the bottom or the side of the oil tub and extend into the oil near the bearing that is being lubricated. A sample drawn from this area of the tub will be more representative of the oil actually lubricating the bearing. Vacuum devices are available that can assist in obtaining the sample.

When using a permanently mounted sample tube, it is important to flush the tube before taking the sample. Flush at least five times the dead volume of the tube before taking the sample. This flushing should remove any contaminants that may have settled in the tube.

The bottle used to take the sample must be very clean to prevent contaminating the sample. ISO 3722 is the standard for the cleanliness of sample bottles. For most applications in hydroplants, a bottle meeting the ISO 3722 requirements for "Super Clean" is recommended. There are several options for bottle material. The type of material is not important. Clear materials, such as glass and Polyethylene Terephthalate (PET) plastic, allow a visual inspection of the oil.

Numerous sizes of bottles are available. The size required depends on the tests to be performed. Coordinate the size of the bottle with the testing laboratory based on the volume of oil required.

5.1.1.2 Field Tests

A visual inspection of an oil sample is the simplest type of field test. Store the sample to be inspected at room temperature away from direct sunlight for at least 24 hours before the inspection. Check the sample for sediment, separated water, unusual color or cloudiness, and any unusual odors. It is a good idea to keep a sample of new, unused oil of the same type and manufacturer stored in a sealed container in a cool dark place for comparison to the used sample with respect to color, odor, and general appearance.

Hazy or cloudy oil may be the result of water contamination. The crackle test can be used to verify the presence of water in oil but does not give any quantitative results. Conduct the crackle test by making a small cup from aluminum foil, adding a few drops of the oil, and heating rapidly with a small flame or by immersing a hot soldering iron in a sample of the oil. In either method, an audible crackling sound will be heard if water is present. Wear eye protection during the test because oil may splatter while being heated.

If water or sediment is found during the visual inspection, purify the oil and send samples of the unpurified oil and the purified oil to a laboratory for analysis. In this way, the sediment of the unpurified oil can be analyzed to determine its source, and the condition of the purified oil can be verified as safe for continued use.

Test kits are available that allow the oil's neutralization number to be determined in the field. With the exception of some motor oils, which may be alkali to counteract acidic products of combustion, most lubricating oils are essentially neutral. If an oil is found to be acidic, it is likely the result of oxidation of the oil caused by extended service or abnormal operating conditions. The neutralization number of new oil is usually less than 0.08. The maximum allowable number depends on the type of oil and its service and should be obtained from the oil manufacturer. The maximum value is usually less than 0.5. Of greatest concern in this test is the rate of increase and not necessarily the neutralization number itself. A sudden increase in the neutralization number may indicate that an operational problem exists or that the oil has reached the end of its useful life. In either case, action is required before further deterioration and equipment damage occurs. If a large increase in the neutralization number is noted or if the number exceeds the maximum allowable, contact the oil's manufacturer to determine what, if anything, can be done to reclaim the oil.

Equipment is also available to allow tests such as viscosity, water content, and particle count to be done onsite. Doing these tests onsite saves time and allows quick decisions to be made concerning filtering or other maintenance, but unless a facility does a large volume of lubricant testing, having these tests done by a laboratory is likely more cost effective.

5.1.1.3 Laboratory Tests

Periodic laboratory testing should be performed to include viscosity, water content, total acid number, particle count, and elemental analysis for wear metals and additives. Also, it may be necessary to perform a Rotating Pressure Vessel Oxidation Test (RPVOT), which is a test to determine the oil resistance to oxidation and an indication of the condition of the oxidation inhibitor in the oil. This test is not required as part of the regular testing schedule, but based on the initial testing, the laboratory may recommend this or other tests. These tests can usually be accomplished by any laboratory equipped for lubricant testing, but preferably the tests should be performed by someone knowledgeable in the use and formulation of the lubricants being tested. Because the composition and additive content of oils is usually considered proprietary information, the manufacturer may have to be contacted to determine the extent of additive depletion. Also, contact the manufacturer anytime the tests indicate there is some question about the continued serviceability of an oil.

5.1.1.4 Test Schedule

Refer to the parent FIST for the specific oil testing schedule of a component or system. Samples should be drawn from component systems periodically. A visual inspection of the samples should be performed, and the samples should be submitted for laboratory analysis. More frequent testing may be warranted if a visual inspection of the oil indicates the presence of water or sediment, or if previous laboratory tests indicated a sudden increase in contaminants or oxidation products. In most cases, a standard periodic laboratory test is sufficient.

5.1.1.5 Oil Purification and Filtration

For a lubricating or hydraulic oil to perform properly, it must be kept free of contaminants. In hydroelectric powerplants, water is the most common contaminant. The presence of water in oil may promote oxidation, corrosion, sludge formation, foaming, or additive depletion, generally reducing an oil's effectiveness. Solid contaminants such as dirt, dust, and wear particles may also be present. These solid particles may increase wear, promote sludge formation and foaming, and restrict oil flow within the system. The correct frequency of purification, filtration or replacement should be determined based on the results of an oil testing program.

The oil from large bearings and governor sumps should periodically be drained and filtered, and the oil reservoir or sump thoroughly cleaned. The most efficient method of determining when to filter is through the results of the oil tests. Filtering more frequently than is necessary is a waste of time, while waiting too long to filter the oil will shorten the oil's life and potentially damage the equipment being lubricated.

The oil from small bearings should be drained periodically, and the reservoir or case cleaned and filled with new oil. Care should be taken when filling a bearing oil reservoir so as not to under or over fill. In many cases, over filling an oil reservoir can cause as much damage as under filling

The following are some of the most common purification or filtration methods:

5.1.1.5.1 Gravity Purification

Gravity purification is the separation or the settling of contaminants that are heavier than the oil. Gravity separation occurs while oil is in storage but is usually not considered an adequate means of purification for most applications. Use other purification methods in addition to gravity separation.

5.1.1.5.2 Centrifugal Purification

Centrifugal purification is gravity separation accelerated by the centrifugal forces developed by rotating the oil at high speed. Centrifugal purification is an effective means of removing water and most solid contaminants from the oil. The rate of purification depends on the viscosity of the oil and the size of the contaminants.

5.1.1.5.3 Mechanical Filtration Mechanical filtration removes contaminants by forcing the oil through a filter medium with holes smaller than the contaminants. Mechanical filters with a fine filter medium can remove particles as small as 1 micron. The filter medium of a mechanical filter requires periodic replacement as the contaminants collect on the medium's surface. Kidney loop filters have been successfully used at various Reclamation facilities when installed on individual bearing or governor sumps.

When choosing a filter medium, specify the Beta rating rather than a nominal rating. The nominal rating some filter manufacturers may use is an arbitrary rating that means the filter stops most particles at the nominal size. The Beta rating is a filter rating expressed as the ratio of the particles at a given size or larger entering the filter to the number of the same sized particles leaving the filter. For example, a Beta rating of β_2=200 means that for every 200 particles greater than 2 microns that entered the filter, only 1 particle would leave the filter. Likewise, a β_5 = 1,000 filter would remove 999 out of every 1,000 particles 5 microns and bigger. For most equipment in hydroplants, a β_5 = 200 filter is sufficient, but if cleaner oil is desired, a β_2=200 can be used. Before using a filter finer than a β_5 = 200, contact the oil manufacturer to verify what it recommends for a minimum filter rating. Some additives may be filtered out of the oil if the filter medium is too fine.

5.1.1.5.4 Coalescence Purification

A coalescing filter system uses special cartridges to combine small, dispersed water droplets into larger ones. The larger water drops are retained within a separator screen and fall to the bottom of the filter while the dry oil passes through the screen. A coalescing filter also removes solid contaminants by the mechanical filtration principle.

5.1.1.5.5 Vacuum Dehydration

A vacuum dehydration system removes water from oil through the application of heat and vacuum. The contaminated oil is exposed to a vacuum and is heated to temperatures of approximately 100 to 140 ºF (38 to 60 ºC). The water is removed as a vapor. Take care so that some of the desirable, low-vapor-pressure components or additives are not removed by the heat or vacuum.

5.1.1.5.6 Adsorption Purification

Adsorption or surface attraction purification uses an active media, such as Fuller's earth, to remove oil oxidation products by their attraction or adherence to the large internal surfaces of the media. This is a common method of purifying transformer insulating oils. **Note: This method also removes most of an oil's additives and should not be used for turbine or hydraulic oil purification.**

5.1.2 Operating Temperature

A recommended range for the oil operating temperature for a particular application is usually specified by the equipment manufacturer. Exceeding this range may reduce the oil's viscosity to the point that it can no longer provide adequate lubrication. Subjecting oil to high temperatures also increases the oxidation rate. For every 18 ºF (10 ºC) increase above 150 ºF (66 ºC), an oil's oxidation rate doubles, which means the oil's life is essentially cut in half. This is especially critical for turbine oil in hydroelectric generating units where the oil is expected to last for years. Typically, the ideal range for turbine oil is between 120 and 140 ºF (50 and 60 ºC), although in many cases, the actual operating temperature may be below this range. If the oil operates consistently above this range, some problem, such as misalignment, tight bearings, or clogged cooling lines, may exist and should be corrected. If it is necessary to operate at higher temperatures, check the oil's neutralization number more frequently. An increase in the neutralization number indicates the oxidation inhibitors have been used up and the oil is beginning to oxidize. Contact the lubricant manufacturer for recommendations regarding the continued use of the oil.

5.1.3 Oil Compatibility

When it becomes necessary to replenish an oil lubrication system, the best practice is to always use oil that is identical to the oil already in the system. Mixing incompatible oils is a possible source of contamination or degradation. Many of Reclamation's field offices have expressed concerns about mixing different brands of similar turbine oil. It is common practice to procure make-up oil to replace oil that has been lost over the years due to leaks, filtering losses, evaporation, and losses that occur due to routine maintenance. Similar oils made by different manufacturers for the same service may be incompatible because of different additives in the oils. The additives may react with one another, depleting the additives and leaving the oil unable to perform as it was intended.

If the exact type or brand of the existing oil is not known, the best option is to completely replace the oil supply. The cost to repair the damage caused by incompatible oils in most cases will outweigh the cost of the new oil. If a system is converted to a different lubricant, it is recommended that the entire system be cleaned and thoroughly flushed before the new lubricant is added. ASTM Standard D 6439-11(2017), *Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems*, provides guidance for flushing bearing systems.

In larger systems where there is a very large volume of oil, and the existing oil is still in good condition, complete replacement may not be feasible. In these cases, the make-up oil should be formulated using the same type of base oil as the existing oil, Group I in many cases, and a compatibility test such as Federal Test Method (FTM) 791C should be performed. While the test is not quantitative, it will give some indication of precipitate formation. Even if tests show that two different oils are compatible, it is always prudent to check the oil more frequently if a different makeup oil is used. The oil and components should be checked for signs of foaming, precipitate, or overheating.

This incompatibility problem arose from the change in the type of base oil used by many manufacturers, or more accurately, the type of refining process used to process the base oil. Until the mid-1990s, most base oil stock was refined by the solvent refining process. This process uses solvents to remove some of the impurities of the crude oil. Solvent-refined base oils are commonly referred to as Group I oils. In the mid-1990s, many manufacturers started using base oils that are refined by hydrocracking. This process adds hydrogen at high temperatures and pressures to remove impurities and change the molecular structure of some of the molecules. Oil refined by hydrocracking is referred to as Group II oil. Group II oil is a purer oil that offers better thermal and oxidation stability, lower toxicity, increased biodegradability, improved low temperature flow, and a generally longer life than a comparable Group I oil. Because of the superior characteristics, most oil companies are changing to Group II base oils for their turbine oil formulations.

Group I and Group II base oils are not necessarily incompatible, but the additive packages used in the oils may be incompatible. An example of this incompatibility occurred at a Corps of Engineers plant. In this case, the existing Group I oil was replaced by a Group II oil. The original oil used a silicone-based antifoaming additive. The silicon-based additive was easily held in solution in a Group I base oil but did not dissolve in a Group II base oil. When the new Group II oil was put in service, the antifoaming additive in the residual Group I oil precipitated out of solution and coated everything in contact with the lubricant. If the mixing occurs in a bearing housing or governor sump, the precipitate coats bearing surfaces, clogs filters and valves, and likely requires at least partial disassembly to clean. If the mixing occurs in a storage tank, the entire volume of oil in the tank may be contaminated and, at a minimum, require an extensive reclaiming process to make the oil acceptable for use.

While there are tests for oil compatibility, the tests are not quantitative, and certification of compatibility by a test laboratory or a manufacturer is difficult or impossible to obtain. The tests are pass/fail, and no reference standard is available for the accuracy of these tests. Requiring a compatibility test as part of a specification for makeup oil may not guarantee that the new oil is compatible with the existing oil.

Even if tests show that two different oils are compatible, it is always prudent to check the oil more frequently if a different makeup oil is used. Check the oil and bearing for signs of foaming, precipitate, or overheating. If a system is converted to a different lubricant, it is recommended that the entire system be cleaned and thoroughly flushed before the new lubricant is added. American Society for Testing and Materials (ASTM) Standard D 6439-99, *Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems*, provides guidance for flushing bearing systems.

5.2 Grease Lubricated Systems

5.2.1 Antifriction Bearings

The most common problem with grease lubrication of antifriction bearings is over-lubrication. The idea that more is better, coupled with the fact that it often is difficult to determine the actual amount of grease in a bearing housing, causes many bearings to be overgreased. Excess grease will churn within the bearing housing and cause excessive heat, which can soften the grease, reducing its effectiveness and leading to overheating of the bearing, causing damage. The heat can also cause the grease to expand, increasing the temperature and creating enough pressure to damage the bearing seals.

Ideally, a grease lubricated antifriction bearing should be "packed" by hand so that the bearing housing is approximately one-third full of grease. Open the bearing housing, remove the bearing and all of the old grease, and thoroughly clean the bearing and the housing. Do not use compressed air for cleaning or drying the bearing because moisture in the air may induce corrosion in the highly polished bearing surfaces. When clean, thoroughly pack the bearing in new grease and fill the bearing housing one-third full of grease.

It is not always practical or possible to hand pack a bearing. In these cases, grease guns or other high-pressure devices may be used. Exercise caution when using high-pressure systems to prevent overgreasing or creating excess pressure in the bearing housing. When grease is applied using a grease gun, remove the relief plug, if equipped, so that, as the new grease is applied, all the old grease is purged from the bearing housing. Operate the machine for approximately 30 minutes before replacing the plug to allow excess grease to escape. If the bearing housing does not have a relief plug, add grease very infrequently to prevent overgreasing. After grease is added, remove the pressure fitting, or “zerk,” to prevent pressure retention.

5.2.2 Journal Bearings or Bushings

Grease lubricated bushings or journal bearings are not as sensitive to over-lubrication as antifriction bearings, so “hand packing” is not usually necessary. The most common method of applying grease to a journal bearing is by a high-pressure system. This may be a centralized, automatic system, as is used on turbine wicket gates, or it may be a grease gun. Overgreasing with a high-pressure system does not normally damage a journal bearing, but it can damage seals, waste grease, and cause a mess.

The most common problem encountered with centralized greasing systems is plugging of the lines. Regularly check all points that are to be lubricated to ensure they are receiving grease. If clogging of the lines is a persistent problem, it may be necessary to switch to a grease with a lighter consistency or less adhesiveness or adjust the cycle frequency and volume of grease per cycle.

5.2.3 Grease Compatibility

Mixing two greases frequently results in a product inferior to either of the component greases. The mixture may be softer in consistency, less resistant to heat, and have a lower shear stability. When this happens, the greases are considered incompatible. Incompatibility of greases is normally a result of the incompatibility of the thickening agents of the component greases. Table 2 lists the compatibility of some of the most common types of greases. Note that this table is intended only as a guide. In some instances, grease types listed as compatible may be incompatible because of adverse reactions between the thickening agent of one grease and additives in the other. In rare cases, greases with the same thickening agent but made by different manufacturers may be incompatible because of the additives.

If it becomes necessary to change the type of grease used in a piece of equipment, thoroughly clean the bearing housing or the area being greased to remove all of the old grease. If this is not possible, flush out as much of the old grease as possible using the new grease during the initial application and increase the greasing frequency until it is determined that all of the old grease has been purged from the system.

Table 2.—Grease compatibility

Grease Compatibility														
Grease	**Aluminum complex**	**Barium**	**Calcium**	**Calcium complex**	**Calcium 12 Hydroxy**	**Calcium Stearate**	**Calcium Sulfonate**	**Clay**	**Lithium**	**Lithium Complex**	**Lithium 12 Hydroxy**	**Lithium Stearate**	**Polyurea**	**Sodium**
Aluminum Complex	C	I	I	I	C	I	B	I	I	C	I	I	I	I
Barium	I	C	I	I	C	NI	B	I	I	I	I	NI	I	I
Calcium	I	I	C	B	C	NI	I	C	C	C	B	NI	I	I
Calcium Complex	I	I	B	C	B	I	C	I	I	C	I	I	C	I
Calcium 12 Hydroxy	C	C	C	B	C	C	NI	B	C	C	C	C	I	I
Calcium Stearate	I	NI	NI	I	C	C	B	C	NI	C	B	C	I	NI
Calcium Sulfonate	B	B	I	C	NI	B	C	B	C	C	B	B	B	I
Clay	I	I	C	I	B	C	B	C	I	I	I	I	I	I
Lithium	I	I	C	I	C	NI	C	I	C	C	C	NI	I	B
Lithium Complex	C	I	C	C	C	C	C	I	C	C	C	C	I	B
Lithium 12 Hydroxy	I	I	B	I	C	B	B	I	C	C	C	C	I	I
Lithium Stearate	I	NI	NI	I	C	C	B	I	NI	C	C	C	I	NI
Polyurea	I	I	I	C	I	I	B	I	I	I	I	I	C	I
Sodium	I	I	I	I	I	NI	I	I	B	B	I	NI	I	C

B – Borderline compatibility
C – Compatible
I – Incompatible
NI – No information on compatibility

6.0 Lubricant Storage and Handling

6.1 Safety

When handled properly, most lubricants are safe; when handled improperly, some hazards may exist. The Safety Data Sheet (SDS) provides information on the potential hazards associated with a specific lubricant and should be readily accessible to all personnel involved in any way in the handling of lubricants. Each lubricant's SDS provides information on any hazardous ingredients, physical and chemical characteristics, fire and explosion data, health hazards, and precautions for safe use.

6.2 Oil

Most powerplants use a bulk storage system with separate clean and dirty oil tanks to store the oil for the guide bearings and governors. At times, the clean oil tank can become contaminated by water condensation or dust or dirt in the air. To prevent the contamination of the bearing or governor oil reservoirs, filter the oil from the clean tank again as it is being pumped into these reservoirs. If this is not possible, direct the initial oil drawn from the clean tank into the dirty oil tank to remove any settled contaminants.

Periodically drain and thoroughly clean the clean oil storage tank. If the area where the storage tanks are located is dusty, it may be desirable to install a filter in the tank's vent line. If water contamination is persistent or excessive, a desiccant breather may be required.

Store oil in drums indoors, if possible, following label directions as they pertain to special precautions regarding temperature or ventilation requirements. If it is necessary to store drums outside, store them on their side to prevent water or dirt from collecting on top of the drum. Always keep the bungs on the drums tightly closed, except when oil is being drawn out. If a tap or pump is installed on the drum, wipe the outlet clean after drawing oil to prevent dust from collecting.

When dispensing oil from bulk storage, such as a drum or tank, dispense it only into clean, closed containers to prevent contamination. Mark the containers for the oil they are to be used with to prevent mixing incompatible oils.

6.3 Grease

Characteristics of some greases may change in storage. A grease may bleed, change consistency, or pick up contaminants during storage. Because some greases may be more susceptible to the effects of prolonged storage than others, consult the manufacturer or distributor for information on the maximum shelf life of a particular grease. To be safe, do not store more than a 1-year supply of a grease at any time. Store grease in a tightly sealed container away from furnaces or heaters to prevent dust, moisture, other contamination, or exposure to excessive heat. Excessive heat may cause the grease to bleed and oxidize.

7.0 Lubricant Selection

When choosing a lubricant for a particular piece of equipment, consult the equipment manufacturer's operation and maintenance manual. The operation and maintenance manual usually outlines the required characteristics of the lubricants as well as a recommended schedule for replacement or filtering. If the maintenance manual is not available, or is vague in its recommendations, contact the lubricant manufacturer or distributor for this information. Provide all the pertinent information on the equipment, such as operating speed, frequency of operation, operating temperature, and any other special or unusual conditions, to the lubricant manufacturer or distributor so that a lubricant with the proper characteristics can be chosen. Use prudence when dealing with a lubricant salesperson to prevent purchasing an expensive lubricant with capabilities in excess of what is required.

Whenever possible, purchase lubricants that can be used in several applications. Limiting the number of lubricants onsite minimizes the chance of mixing different lubricants or using the wrong lubricant.

7.1 Lubricant Standards

A number of tests and standards have been developed to define and measure the properties of lubricants. Most of these tests have been standardized by ASTM. The properties determined by these tests can be very helpful in comparing relative performance of several lubricants, but note that many of these tests have little correlation to actual service conditions. When selecting a lubricant, review the test procedures for the required properties to keep the relevance of the test in perspective.

7.2 Turbine Oil

Under normal conditions, the lubricating oil for a hydroelectric unit's guide and thrust bearings experiences relatively mild service, but is expected to have a long service life. A long service life requires a high-quality oil with various additives to enhance and maintain its quality.

Most powerplants use a highly refined turbine oil for bearing lubrication. Table 3 lists some typical properties of a Group I turbine oil. A Group II oil would have better oxidation stability. The oil should be rust and oxidation inhibited with an antifoam additive. The oil should also be resistant to emulsification and separate readily from water. Antiwear or extreme pressure additives are not required or desired.

Table 3.—Typical Oil Specifications

Typical Specifications For Turbine Oil				
Characteristics	ISO viscosity grade 32	ISO viscosity grade 46	ISO viscosity grade 68	ASTM Test No.
Viscosity, centistokes at 40 ºC	28.8 – 35.2	41.4 –50.6	61.2 – 74.8	D 445
Viscosity Index, minimum	94	94	94	D 2270
Pour Point, ºC maximum	-6	-6	-6	D 97
Flash Point, ºC minimum	180	180	180	D 92
Total Acid Number, mg KOH/g	Report	Report	Report	D 974
Rust Preventive Characteristics	Pass	Pass	Pass	D 665A
Foaming Characteristics Sequence 1, mL maximum	50/0	50/0	50/0	D 892
Air Release, 50 ºC, minutes max	5	7	10	D 3427
Emulsion Characteristics @ 54 ºC, minutes to 3 mL emulsion max	30	30	30	D 1401
Oxidation Stability Hours to neutral. No. 2.0 minimum Minutes to 175 kPa drop, minimum	 2000 350	 2000 350	 2000 175	 D 943 D 2272

The equipment manufacturer usually specifies the recommended oil viscosity, which depends on the operating speed, load, and temperature, as well as the bearing clearances. The most common viscosities used in turbines are the ISO viscosity grades 32, 46, and 68.

7.3 Hydraulic Systems

The primary purpose of hydraulic fluid is to transmit power. To accomplish this effectively, the fluid must be incompressible and flow readily through the system. The fluid must also have sufficient viscosity to seal and lubricate the components of the hydraulic system. A variety of fluids are capable of performing these functions, but the most satisfactory hydraulic fluid is usually oil.

A hydraulic oil has many of the same requirements as a lubricating oil used in the unit bearings, and, in many cases, the same oil can be used. If the system uses a gear pump, operates at pressures less than 1,000 pounds per square inch (psi), and has similar viscosity requirements, the bearing lubricating oil can function very well as a hydraulic oil. Systems that operate over 1,000 psi or use a piston or sliding vane pump usually require a fluid with an antiwear additive. Systems that operate in areas of great temperature extremes may require a multigrade oil to provide desirable high and low temperature viscosity characteristics.

Some instances may require a fire-resistant hydraulic fluid. These fluids are usually either a water-based or a synthetic fluid. In either case, the system must be designed specifically for the fluid it uses. Water-based fluids have a very low viscosity. Synthetic fluids are not compatible with many seal materials found in hydraulic systems.

7.4 Hydraulic Governor Systems

A hydraulic governor system, at its core, is simply a hydraulic system and in most cases can use the turbine oil used in the unit bearings. Some cases, such as low plant temperatures or extremely long control lines, require a lighter viscosity oil than is used in the turbine.

7.5 Wicket Gates, Radial Gates, and Butterfly Valves

Grease for slow moving, highly loaded, bronze bushings, such as those found on wicket gates, radial gates, and butterfly valves, should be adhesive, water resistant, able to withstand high bearing pressures, and of a consistency that can be pumped at the lowest temperature encountered. Usually, a grease with extreme pressure or antiwear capabilities is specified. Note that grease manufacturers use the term “extreme pressure” fairly liberally. Verify the presence of extreme pressure additives and extreme pressure properties. Because the grease is lubricating a bronze bearing, it should not be corrosive to copper. The dropping point of the grease has little relevance in this case.

A great deal of research was conducted on the lubrication of radial gate trunnion bearings following the failure of the Folsom Dam radial gate. Table 4 lists some of the properties of grease recommended for this application as a result of this research. Because wicket gate bushings and butterfly valve trunnion bearings see similar service, the list applies to both.

Table 4.—Recommended grease properties

Recommended Grease Properties for Wicket Gates, Radial Gates, Butterfly Valves				
Grease Property	**Purpose of Property**	**ASTM Test**	**ASTM Test Desired Result**	**Maximum Allowable**
Lubricity	Low static and kinetic friction for bronze on steel	G99-03	Coefficient of static friction, fs (breakaway), 0.10, (b) coefficient of kinetic friction at 0.2 inch/min, fk, 0.10	Fs, 0.15, (b) fk, 0.12
Rust inhibitors	Prevent rust on steel	D1743-01	Pass, no rusting of steel after 48 hrs.	Pass
Copper corrosion	Low corrosion of bronze bushing	D4048-02	1 to 4B	4C
Wear and scuffing resistance	Prevent scuffing between steel and bronze	G99-03	No scuffing or transfer of metal of bronze to steel	No Scuffing
Water washout	Resists washout by water	D1264-00	0% washout	1.9%
Consistency	Easy to pump but thick enough to stay in bushing	D-217-02	NLGI 1 to 1.5	NLGI 2
Oxidation stability	Resistance to oxidation	D-942-02	Pass, no acid formation or discoloration	Pass
Oil separation	Indication of stability in storage	D-1742-94	Less than 0.1% bleeding of oil	1.6% in 24 hours

7.6 Gears

Gears vary greatly in design and in their requirements for lubrication. When selecting a lubricant for any gear application, consider the type of gearing and the operating conditions, such as speed, load, and temperature. Enclosed gears (i.e., gears encased in an oil tight housing) usually use a mineral oil with rust, oxidation, and foam inhibitors and, where loads are severe, extreme pressure additives.

Worm gears are a special case because the action between the worm and its mating gear is sliding, rather than the rolling action found in most gears. The sliding action allows fluid film lubrication to take place. Worm gears are also different in that the mating gears (the worm and the bull gears) are usually made of dissimilar materials. The use of dissimilar material reduces the friction and the chance of galling. Worm gears do not usually require extreme pressure additives, but lubrication can be improved by lubricity additives.

A highly adhesive lubricant is required for most open gear applications. An open gear lubricant must resist being thrown off by centrifugal force or being scraped off by the action of the gear teeth. Most open gear lubricants are heavy oils, many times asphalt based, or soft greases. Depending on the service conditions, oxidation inhibitors or extreme pressure additives may be added. Because these lubricants are very adhesive, they also attract dust and dirt. These contaminants can act as abrasives if the gears are not periodically cleaned.

7.7 Wire Rope

The life of a wire rope can be extended through the proper application of the correct lubricant. The individual wires in a wire rope are subject to abrasive wear as they move relative to each other any time the rope is bent, such as when it goes over a sheave or is wound on a drum. Unless the rope is constructed of stainless steel, it is also subject to corrosion damage. Corrosion is especially a problem for wire ropes that are exposed to the elements.

To be effective, the lubricant must penetrate into the rope to provide lubrication between the individual wires and strands. It also must provide external lubrication to reduce friction between the rope and sheaves or drum, and it should act as a sealant to prevent corrosion. The lubricant coating should not prevent visual inspection of the rope for broken wires or other damage.

Many times, a light mineral oil, such as an SAE 10 motor oil, is used to lubricate wire rope. The advantages of such a light oil are that it can be applied cold and it penetrates into the rope easily. The main disadvantages are that it works out of the rope just as easily as it works in, requiring frequent application.

Heavy, adhesive lubricants can provide longer lasting protection, but most require heating, or in some cases thinning with a solvent, before application to provide proper penetration. A heavy lubricant, when properly applied, not only provides internal lubrication, but also provides a durable outer coating to prevent corrosion and keep dust and abrasives out of the rope.

The lubricant can be applied by brush, spray, dripped on, or, preferably, by passing the rope through a heated reservoir filled with the lubricant. Before applying the lubricant, clean any accumulated dirt, dust, or rust from the rope because they can prevent the lubricant from penetrating properly. Apply the lubricant to the entire circumference of the rope and slowly wind the rope on and off the drum several times to work the lubricant into the rope. If the lubricant is applied by hand, it may be helpful to apply the lubricant as it passes over a sheave because the bending spreads the rope’s strands, allowing the lubricant to penetrate more easily.

7.8 Environmentally Acceptable Lubricants

More stringent regulations on the use, containment, and disposal of lubricants, have generated a great deal of interest in the use of “environmentally friendly” or “environmentally acceptable”

(EA) lubricants (EAL) and hydraulic fluids. The desire is to use products that are less toxic and more readily biodegradable if they are inadvertently released.

Environmentally acceptable lubricants are similar to traditional (mineral oil) lubricants in that they are both made of one of the three types of base oils (mineral, vegetable, or synthetic) blended with an additive package.

A number of terms are used to describe lubricants, such as environmentally acceptable, readily biodegradable, inherently biodegradable, food grade, or non-toxic. Their meanings can be subjective, leading to negative environmental or health consequences if the wrong product is selected. Exercise careful deliberation when selecting EALs for each specific application.

At the time of this document's publication, Reclamation has begun replacing traditional lubricants with EALs at some facilities on specific equipment. The primary reasons for slow adoption of EALs are the relatively recent availability of proven EALs, the potential compatibility risk involved with replacing time-tested traditional lubricants and the increased cost.

Additives are used to change the characteristics of the base oils to increase performance for each application. EALs present a challenge to chemists in that they are limited to additives that are environmentally acceptable. An example of this challenge is with the common antiwear additive ZDDP (zinc dialkyl dithiophosphates). ZDDP does not provide the antiwear protection itself, but the breakdown of it does. ZDDP contains heavy metals and is not considered environmentally acceptable, as it is not readily biodegradable. ZDDP may be beneficial in some gate applications, but not desirable for hydro turbine oil applications as our operating conditions are mild, and the benefit does not outweigh the potential impact to the environment.

Mineral oil based EALs are the least common. Crude oil is inherently not biodegradable; however, a sugar cane based mineral oil that is biodegradable may be suitable for certain applications.

Vegetable oils are inherently less toxic to the environment; however, they are more prone to oxidize and become rancid. Additives are formulated to help reduce this oxidation potential.

Synthetic oils are phenomenal candidates as they can be custom formulated to meet specific needs; however, they can be significantly more expensive.

7.8.1 EAL Selection Criteria

In 2020, Centre for Energy Advancement through Technological Innovation (CEATI) published a testing guideline, Hydraulic Plant Life Interest Group (HPLIG) 03/103, to evaluate EA hydraulic and gear oils. This guide allows Reclamation and CEATI HPLIG members to hold EA manufacturers to a well-defined standard and better respond to potential legislative changes requiring the use of EALs.

The guideline is broken up into two primary testing sections: environmental acceptability and performance testing.

Environmental Acceptability Tests

- Biodegradability
- Toxicity

Performance Tests

- Flash Point
- Pour Point
- Viscosity
- Moisture
- Color
- Acid Number
- Copper Corrosion
- Foam
- Air Release
- Oxidation and RPVOT
- Water Separation
- Particle Counts
- Varnish Potential
- Rust Prevention

Although there are several tests for toxicity and biodegradability from organizations such as the Organization for Economic Co-operation and Development (OECD), ASTM, and ISO, the results of these tests may have very little correlation to the conditions under which the lubricant is actually used. A product may be nontoxic to one organism but toxic to another. Likewise, a product may readily biodegrade under certain test conditions but less so under different conditions. When choosing an EA product, review the test procedures and the results to back up any toxicity and biodegradability claims. Note that at the time of this publication, there is still no global standardized test method for determining biodegradability.

7.8.2 EAL Maintenance

Test EALs that are in use more frequently due to their tendency to biodegrade more quickly. The test results will indicate the need for lubricant replacement. Oxidation stability is usually not as good as with a comparable mineral oil based product. Any water contamination can accelerate the oxidation process. In general, EA products have to be replaced more frequently than a mineral oil based product.