APPENDIX D

Lubrication of Powerplant Equipment Bureau of Reclamation FIST 2-4 July 2004

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Volume 2-4

Lubrication of Powerplant Equipment

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Denver, Colorado

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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. Choosing an appropriate lubricant for a particular application and maintaining the effectiveness of lubricants requires a basic understanding of lubrication theory and the characteristics of lubricants. This document discusses lubrication fundamentals, lubricant characteristics, additives, maintenance of lubrication systems, and the selection of lubricants for common powerplant equipment.

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Hydroelectric Research and Technical Services Group

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Bureau of Reclamation

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1. INTRODUCTION

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 will discuss lubrication fundamentals, lubricant characteristics, additives, maintenance of lubrication systems, and the selection of lubricants for common powerplant equipment.

2. FUNDAMENTALS OF LUBRICATION

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 in 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 layers in between 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 simply 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 will be discussed in more detail later.

To keep the surfaces separated, the fluid pressure must be high enough to support the load. In highly loaded bearings, like thrust bearings and horizontal journal bearings, relatively high fluid pressures are required to support the load. 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.

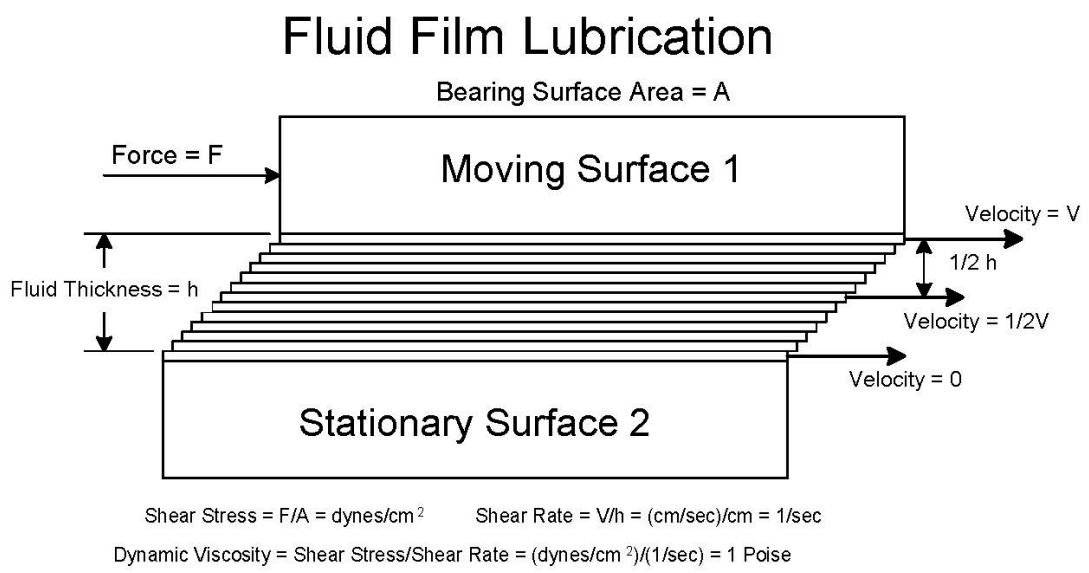

Figure 1.—Fluid Film Lubrication

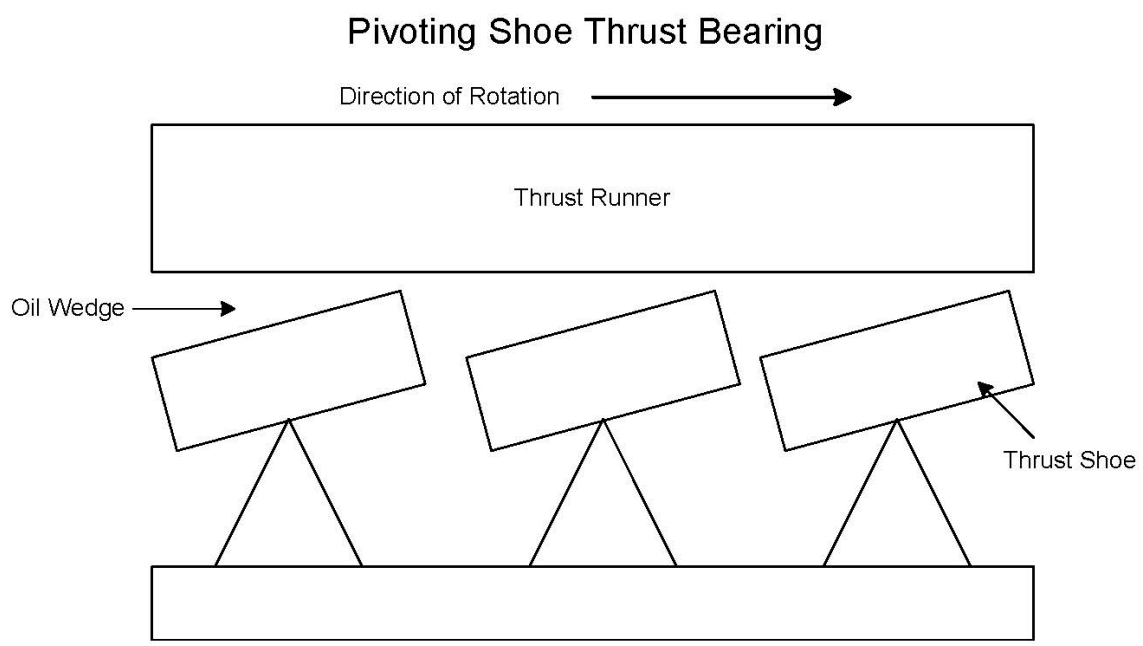

Figure 2.—Pivoting Shoe Thrust Bearing

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 will occur at "J" and not at the bottom of the bearing.

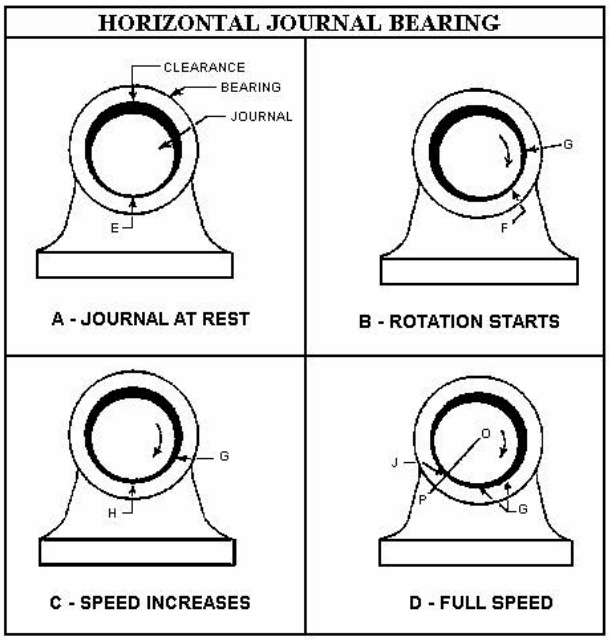

Figure 3.—Horizontal Journal Bearing

(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 Elastohydrodynamic Lubrication

In instances of very high unit loads and high speeds, such as are experienced in antifriction bearings (ball and roller bearings), cams, and some gears, establishing or maintaining an oil film with adequate thickness for normal hydrodynamic lubrication is difficult. In these special cases,

the lubricant is compressed and extremely high pressures are developed. The high pressures increase the lubricant's viscosity and elastically deform the metal surfaces. This allows the load to be spread over a larger area and increases the load carrying capacity. This is referred to as elastohydrodynamic lubrication. In this realm of lubrication, an increase in load deforms the metal surfaces rather than affecting the oil film thickness because the oil film is actually more rigid than the metal.

2.3 Boundary Lubrication

A well-designed fluid film bearing will operate with a full fluid film under most circumstances, but under less than ideal conditions, such as during start up and shut down, the fluid film may become so thin that contact may be made between the rubbing surfaces. This condition is called boundary lubrication and is compared to fluid film lubrication in figure 4. When the bearing surfaces are greatly magnified, peaks on the surface, referred to as asperities, are evident. During boundary lubrication conditions, the asperities of one surface come in contact with the other surface and are torn or worn off. The lubricant's viscosity alone cannot provide sufficient lubrication under these circumstances. To compensate for this, lubricant additives may be required that form an extremely thin boundary film on the bearing surfaces or, in the case of hydroelectric generator thrust bearings, an outside pressure source or hydrostatic system may be used.

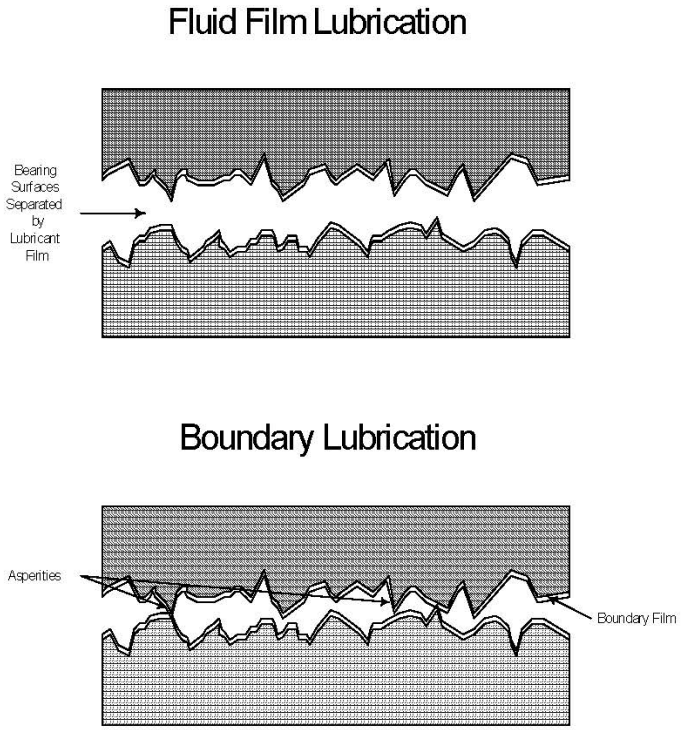

Figure 4.— Fluid Film and Boundary Lubrication

Some reciprocating equipment, such as pistons in compressors or engines, and slow moving equipment, such as turbine wicket gates, rely on boundary lubrication entirely. Gear teeth also depend on boundary lubrication to a great extent. 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, or additive, or both must be maintained. This is accomplished through the use of various extreme pressure, antiwear, and lubricity additives. Solid lubricants, such as graphite, molybdenum disulfide, and 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. 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 petroleum oil, a synthetic oil, or in rare specialized instances, vegetable 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, 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.

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 more than a similar petroleum product.

3.1.2 Oil Characteristics.

3.1.2.1 Viscosity. Probably the single most important characteristic 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. But with the higher internal resistance, temperatures can rise. The correct viscosity for a particular application would be thick enough to support the load but not so thick as to cause excessive fluid friction and a 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 100 ºC, 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 of the 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 210 ºF.

Various organizations have developed grading systems for lubricant viscosity. The most common grading systems now in use have been developed by the International Standards Organization (ISO), the Society of Automotive Engineers (SAE), and the American Gear Manufacturers' Association. It should be noted 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.

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.

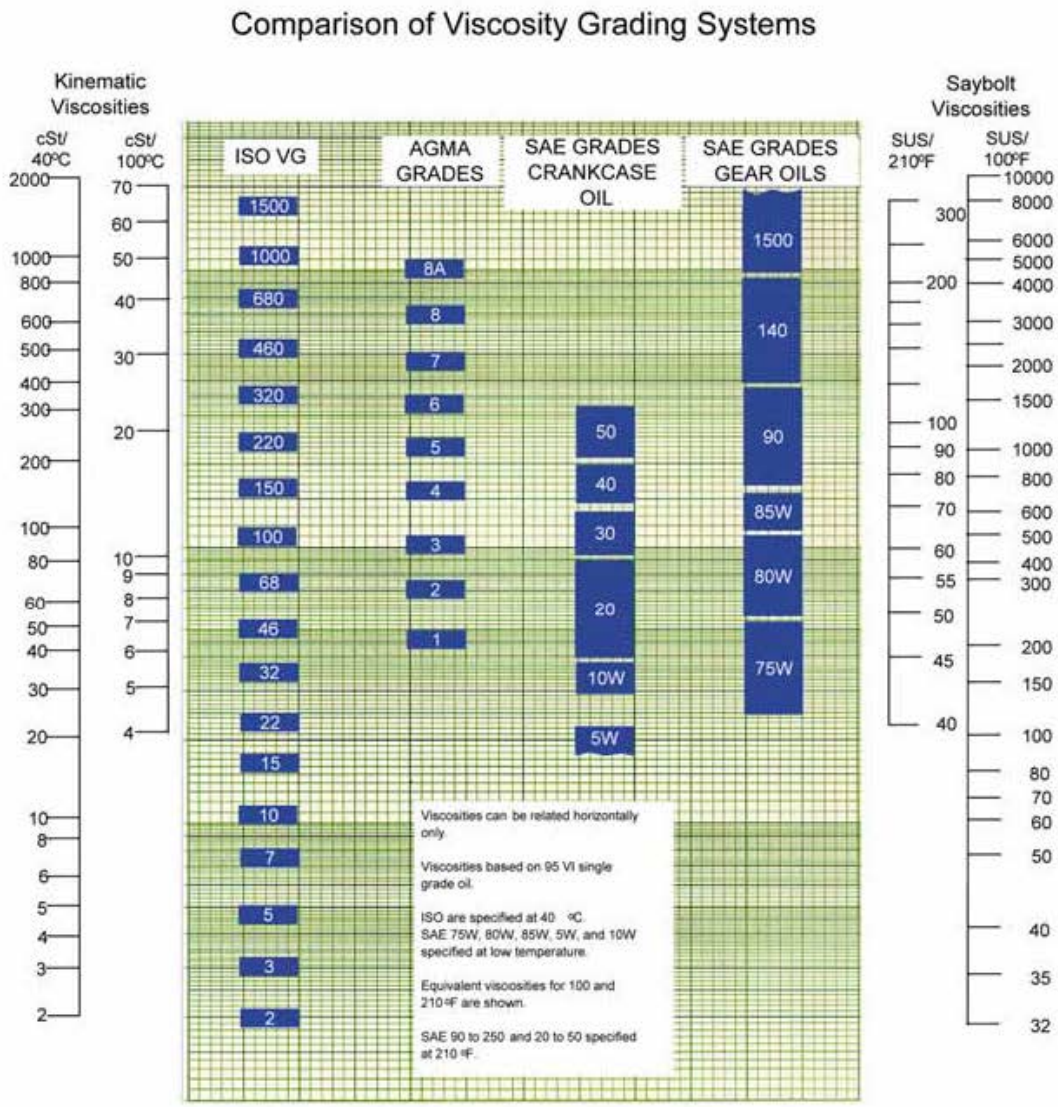

Figure 5.—Viscosity Grading Systems Comparison

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 and 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 alkalies 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 °C	110	163-177	96-104	135-143	177-204	260+	260+	260+	243	260+
Max. Usable Temp °C	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, will 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 a 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 (NGLI) 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 NGLI 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 the long lines and metering valves. 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. At or above the dropping point, a grease will act as a fluid. It should be noted 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 will permanently change 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. LUBRICANT ADDITIVES

Practically all lubricants contain additives to enhance existing properties or to impart new properties. 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 Agent. 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 that resists 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 Depressant. Pour point depressants enable lubricants to flow at low temperature.

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

4.2.4 Emulsifier. 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 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. The lubricant manufacturer should be consulted before this is attempted.

4.5 After Market Additives

There are a number of after market lubricant additives that are being 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 after market 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. Before adding anything to a lubricant, the lubricant's manufacturer should be consulted. The lubricant manufacturer can provide information on the possible benefits or consequences of the additive and determine whether a different lubricant is required.

5. MAINTENANCE OF LUBRICATION SYSTEMS

For a lubricant to perform as intended, some maintenance of the system is required. Care must be taken to ensure that the correct amount and type of lubricant is used and that the lubricant and the system is clean and free of contaminants.

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. By keeping track of the condition of the oil, damage to equipment caused by oil deterioration can be prevented. There are a variety of tests that 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 since 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 the 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 will vary 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 will ensure 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 are going to separate out of the oil. To get a representative sample of the oil, the sample should be taken 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 probably get 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. The bearing should be drained while the oil is still warm. To flush the line and sediment that may be near the drain, at least 1/4 of the oil should be drained out of the tub before the sample is taken.

If the sampling is to be accomplished on a regular basis between filtering, a permanently mounted tube extending into the bearing housing should be used. 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. There are vacuum devices 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. At least five times the dead volume of the tube should be flushed before the sample is taken. 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 PET plastic, allow a visual inspection of the oil.

There are numerous sizes of bottles available. The size required depends on the tests that are going to be performed. The size of the bottle should be coordinated with the testing laboratory based on the volume of oil that they require.

5.1.1.2 Field Tests. A visual inspection of an oil sample is the simplest type of field test. The sample to be inspected should be stored at room temperature away from direct sunlight for at least 24 hours before the inspection. The sample should then be checked for sediment, separated water, unusual color or cloudiness, and any unusual odors. For comparison, 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. The used sample can then be compared to the new 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. The crackle test can be conducted by making a small cup from aluminum foil, adding a few drops of the oil, and heating rapidly with a small flame. The test can also be conducted 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. Eye protection should be worn during the test because oil may splatter while being heated.

If water or sediment is found during the visual inspection, the oil should be purified, and samples of the unpurified oil and the purified oil should be sent 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.

There are test kits 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 that 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 some operational problem exists or that the oil has simply 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, the oil's manufacturer should be contacted to determine what, if anything, can be done to reclaim the oil.

There is also equipment available to allow tests such as viscosity, water content, and particle count to be done onsite. Doing these tests onsite will save time and allow 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 probably more cost effective.

5.1.1.3 Laboratory Tests. Laboratory tests should include viscosity, water content, total acid number, particle count, and elemental analysis for wear metals and additives. A Rotating Pressure Vessel Oxidation Test, which is a test to determine the oil resistance to oxidation and an indication of the condition of the oxidation inhibitor in the oil, should be done periodically as well, but this test is not required as part of the regular testing schedule. Based on the initial testing, other tests may be recommended by the laboratory. The 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. Since 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. The manufacturer should also be contacted anytime the tests indicate there is some question about the continued serviceability of an oil.

5.1.1.4 Test Schedule. Samples should be drawn from all guide bearings and governors annually and submitted for laboratory analysis. In addition to the annual tests, samples should be visually inspected periodically. In most cases, annual laboratory testing is sufficient, but 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 had indicated a sudden increase in contaminants or oxidation products.

If testing is being performed to determine the filtering schedule as part of a condition-based maintenance program, testing should be performed much more frequently. Monthly testing may be required to prevent the oil from degrading to a point that damage could result to the equipment being lubricated.

5.1.2 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, additive depletion, and will generally reduce an oil's effectiveness. Solid contaminants such as dirt or 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. To remove contaminants from the oil, it must be periodically purified. The frequency of purification can be based on the results of the oil testing program or testing simply can be performed periodically. The following are some of the most common purification methods:

5.1.2.1 Gravity Purification. Gravity purification is simply 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. Other purification methods should also be used in addition to gravity separation.

5.1.2.2 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.

5.1.2.3 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 will require periodic replacement as the contaminants collect on the medium's surface.

When choosing a filter medium, the Beta rating should be specified rather than a nominal rating. The nominal rating some filter manufacturers may use is an arbitrary rating that means the filter will stop 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, the oil manufacturer should be contacted 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.

5.1.2.4 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 will also remove solid contaminants by the mechanical filtration principle.

5.1.2.5 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 °F (38 to 60 °C). The water is removed as a vapor. Care must be taken so that some of the desirable, low-vapor-pressure components or additives are not removed by the heat or vacuum.

5.1.2.6 Adsorption Purification. Adsorption or surface attraction purification uses an active media, such as fullers 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. **This method will also remove most of an oil's additives as well and should not be used for turbine or hydraulic oil purification.**

5.1.3 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 °F (10 °C) increase above 150 °F (66 °C), an oil's oxidation rate doubles, which means the oil's life is essentially cut in half. This is especially critical to 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 °F (50 and 60 °C), 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, the oil's neutralization number should be checked more frequently. An increase in the neutralization number indicates the oxidation inhibitors have been used up and the oil is beginning to oxidize. The lubricant manufacturer should be contacted for recommendations regarding the continued use of the oil.

5.1.4 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. 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, causing a depletion of these additives and leaving the oil unable to perform as it was intended.

Another possible incompatibility problem is 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 over to Group II base oils for their turbine oil formulations.

The Group I and Group II base oils themselves are not necessarily incompatible, but the additive packages used in the oil may very well 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 an antifoaming additive that was silicone based. The silicon-based additive is easily held in solution in a Group I base oil but will 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 will coat bearing surfaces, clog filters and valves, and will likely require 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 simply pass-fail, and there is no reference standard 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. The oil and bearing should be checked 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 the grease lubrication of antifriction bearings is overlubrication. Excess grease will churn within the bearing housing and cause excessive heat, which can soften the grease, reducing its effectiveness and leading to bearing damage. The heat can also cause the grease to expand, increasing the temperature further, 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. The bearing housing should be opened, the bearing and all of the old grease removed, and the bearing and the housing thoroughly cleaned. Compressed air should not be used for cleaning or drying the bearing because moisture in the air may induce corrosion in the highly polished bearing surfaces. When clean, the bearing should be thoroughly packed in new grease and the bearing housing filled 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. Caution should be exercised when using high-pressure systems to prevent overgreasing or creating excess pressure in the bearing housing. When grease is applied using a grease gun, the relief plug, if so equipped, should be removed so that, as the new grease is applied, all the old grease is purged from the bearing housing. The machine should be operated approximately 30 minutes before the plug is replaced to allow excess grease to escape. If the bearing housing does not have a relief plug, grease should be added very infrequently to prevent overgreasing, and after grease is added, the pressure fitting, or "zerk," should be removed to prevent pressure retention.

5.2.2 Journal Bearings or Bushings. Grease lubricated bushings or journal bearings are not as sensitive to overlubrication 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 simple grease gun. Overgreasing with a high-pressure system will 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. All points that are to be lubricated should be checked regularly to ensure they are receiving grease. If clogging of the lines is a persistent problem, switching to a grease with a lighter consistency or less adhesiveness or adjusting the cycle frequency and the volume of grease per cycle may be necessary.

5.2.3 Grease Compatibility. The mixing of two greases many times will result 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. It should be noted 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, the bearing housing or the area being greased should be thoroughly cleaned to remove all of the old grease. If this is not possible, as much of the old grease as possible should be flushed out by the new grease during the initial application and the greasing frequency should be increased until it is determined that all of the old grease has been purged from the system.

6. LUBRICANT STORAGE AND HANDLING

6.1 Safety

When handled properly, most lubricants are safe; when handled improperly, some hazards may exist. The Material Safety Data Sheet (MSDS) 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. The lubricant's MSDS should provide information on any hazardous ingredients, physical and chemical characteristics, fire and explosion data, health hazards, and precautions for safe use.

Table 2.—Grease Compatibility

Grease Compatibility														
Grease	Aluminum Complex	Barium	Calcium	Calcium Coumplex	Calcium 12 Hydroxy	Calcium Stearate	Calcium Sulfanate	Clay	Lithium	Lithium Complex	Lithium 12 Hydroxy	Lithium Stearate	Polyrea	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 Coumplex	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 Sulfanate	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
Polyrea	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

6.2 Oil

In most powerplants, a bulk storage system with separate clean and dirty oil tanks is used 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, the oil from the clean tank should be filtered again as it is being pumped into these reservoirs. If this is not possible, the initial oil drawn from the clean tank should be directed into the dirty oil tank to remove any settled contaminants.

The clean oil storage tank should be periodically drained and thoroughly cleaned. 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.

Oil stored in drums, if possible, should be stored indoors, following label directions as they pertain to special precautions regarding temperature or ventilation requirements. If it is necessary to store drums outside, they should be stored on their side to prevent water or dirt from collecting on top of the drum. The bungs on the drums should always be kept tightly closed except when oil is being drawn out. If a tap or pump is installed on the drum, the outlet should be wiped 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. The containers should be marked 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, the manufacturer or distributor should be consulted for information on the maximum shelf life of a particular grease. To be safe, no more than a 1-year supply of a grease should be in storage at any time. Grease should be stored in a tightly sealed container to prevent dust, moisture, or other contamination, and stored where it will not be exposed to excessive heat, such as near furnaces or heaters. Excessive heat may cause the grease to bleed and oxidize.

7. LUBRICANT SELECTION

When choosing a lubricant for a particular piece of equipment, the equipment manufacturer's operation and maintenance manual should be consulted. The operation and maintenance manual will usually outline 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, lubricant manufacturers and distributors are other sources of information. All the pertinent information on the equipment, such as operating speed, frequency of operation, operating temperature, and any other special or unusual conditions, should be provided to the lubricant manufacturer or distributor so that a lubricant with the proper characteristics can be chosen. Some discretion should be used when dealing with a lubricant salesperson to prevent purchasing an expensive lubricant with capabilities in excess of what is required.

Whenever possible, lubricants should be purchased that can be used in several applications. By limiting the number of lubricants onsite, the chance of mixing different lubricants or using the wrong lubricant is minimized.

7.1 Lubricant Standards

There are a number of tests and standards that 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 it should be noted that many of these tests have little correlation to actual service conditions. When selecting a lubricant, the test procedures for the required properties should be reviewed so that the relevance of the test is kept 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 it is expected to have a long service life. To have a long life, a high quality oil with various additives to enhance and maintain its quality is required.

In most powerplants, a highly refined turbine oil is used 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 Turbine Oil Specifications

TYPICAL SPECIFICATIONS FOR TURBINE OIL				
Characteristics	ISO VISCOSITY GRADE			ASTM TEST NO.
	32	46	68	
Viscosity, centistokes @ 40 °C	28.8 – 35.2	41.4 –50.6	61.2 – 74.8	D 445
Viscosity Index, minimum	94	94	94	D 2270
Pour Point, °C maximum	-6	-6	-6	D 97
Flash Point, °C 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 °C, minutes max	5	7	10	D 3427
Emulsion Characteristics @ 54 °C, minutes to 3 mL emulsion max	30	30	30	D 1401
Oxidation Stability Hours to neut. No. 2.0 min Minutes to 175 kPa drop, min	 2000 350	 2000 350	 2000 175	 D 943 D 2272

The recommended oil viscosity is usually specified by the equipment manufacturer and 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. There are a variety of fluids 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. In systems that operate over 1,000 psi or use a piston or sliding vane pump, a fluid with an antiwear additive is usually required. Where the system operates in an area of great temperature extremes, a multigrade oil may be required to provide desirable high and low temperature viscosity characteristics.

In some instances, a fire-resistant hydraulic fluid may be required. 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 will use. Water-based fluids have a very low viscosity, and the synthetic fluids are not compatible with many seal materials found in hydraulic systems.

7.4 Hydraulic Governor Systems

A hydraulic governor system is simply a hydraulic system and in most cases can use the turbine oil used in the unit bearings. In some cases, such as low plant temperatures or extremely long control lines, a lighter viscosity oil than is used in the turbine may be required.

7.5 Wicket Gates, Radial Gates, and Butterfly Valves

Grease for the 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. It should be noted that the term, "extreme pressure," is used fairly liberally by grease manufacturers, and the presence of extreme pressure additives and extreme pressure properties should be verified. 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 them as well.

7.6 Gears

Gears vary greatly in design and in their requirements for lubrication. When selecting a lubricant for any gear application, the type of gearing and the operating conditions, such as speed, load, and temperature, must be considered. 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.

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

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. Extreme pressure additives are usually not required for worm gears, 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 lubrication externally 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 the 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 is that it can be applied cold and it will penetrate into the rope easily. The main disadvantage is that it will work out of the rope just as easily as it works in, and frequent application will be required.

Heavy, adhesive lubricants can provide longer lasting protection, but most require heating before application to provide proper penetration. A heavy lubricant, when properly applied, will not only provide internal lubrication, but also provide a durable outer coating to prevent corrosion and keep dust and abrasives out of the rope. Heavy adhesive lubricants usually must be heated or thinned with a solvent to ensure they provide internal lubrication.

The lubricant can be applied by brush, spray, or 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. The lubricant should be applied to the entire circumference of the rope and the rope slowly wound on and off the drum several times to work the lubricant into the rope. If the lubricant is being applied by hand, it may be helpful to apply the lubricant as it passes over a sheave because the rope's strands are spread by the bending, and the lubricant can penetrate more easily.

7.8 Environmentally Acceptable Lubricants

With more stringent regulations on the use, containment, and disposal of lubricants, a great deal of interest has been generated in the use of "environmentally friendly" or "environmentally acceptable" (EA) lubricants and hydraulic fluids. The desire is to use products that are less toxic and more readily biodegradable if they are inadvertently released to the environment. Unfortunately, at this time, there are no generally accepted industry standards for these products. Although there are tests for toxicity and biodegradability, the results of these tests may have very little correlation to the conditions under which the lubricant will actually be 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, the test procedures, as well as the results, should be provided to back up any toxicity and biodegradability claim.

EA lubricating oils and hydraulic fluids in use should be tested frequently. The properties that allow these products to biodegrade more quickly are not always conducive to long life. Oxidation stability is usually not as good as with a comparable mineral oil-based product. Any water contamination can accelerate the oxidation. In general, the EA products will have to be replaced more frequently than a mineral oil-based product.

8. REFERENCES

Asseff, P.A., *Lubrication Theory and Practice,* The Lubrizol Corporation.

Bloch, H.P., *Practical Lubrication for Industrial Facilities*, Fairmont Press, 2000

Conoco Inc., *Lubrication Manual,* 1981.

Ehrlich, M. (Ed), Lubricating Grease Guide, *National Lubricating Grease Institute,* 1st Edition, Kansas City, Missouri, 1984.

Exxon Corporation, *Proving Ground,* 1988.

Fein, R.S., and F.J. Villforth, Lubrication Fundamentals, *LUBRICATION*, vol. 59, October-December 1973.

Pirro, D.M., A.A. Wessol, *Lubricant Fundamentals*, 2nd Edition, Marcel Dekker, Inc., 2001.

Rein, S.W., Viscosity-I, *LUBRICATION*, vol. 64, No. 1, 1978.

Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas and Hydroelectric Turbine Lubrication Systems, ASTM Standard No. D6439-99.

Troyer, D., and J. Fitch, *Oil Analysis Basics*, Noria Corporation, 2001.

U.S. Army Corps of Engineers, *Lubricants and Hydraulic Fluids*, Engineering Manual 1110-2-1424, 1999.

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to 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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