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Phone: +61 (0) 402 731 563
Fax: +61 8 9457 8642
Email: info@lifetime-reliability.com
Website: www.lifetime-reliability.com

This document is a summary of...

Lubrication for Journal Bearings

Introduction

The objective of lubrication is to reduce friction, wear and heating of machine parts that move relative to each other.

Types of lubrication

Five distinct form of lubrication may be identified:

1. **Hydrodynamic**
2. **Hydrostatic**
3. **Elastohydrodynamic**
4. **Boundary**
5. **Solid film**

Hydrodynamic lubrication suggests that the load-carrying surfaces of the bearing are separated by a relatively thick film of lubricant, so as to prevent metal to metal contact, and the stability thus obtained can be explained by the laws of fluid mechanics. Hydrodynamic lubrication depends on the existence of an adequate supply of lubrication at all times rather than having lubrication under pressure. The film pressure is created by moving surface itself pulling the lubricant into a wedge-shaped zone at a velocity sufficiently high to create the pressure necessary to separate the surfaces against the load on the bearing.

Hydrostatic lubrication is obtained by introducing the lubricant (can be air, water) into the load-bearing area at a pressure high enough to separate the surfaces with a relatively thick film of lubricant. In contrast to hydrodynamic lubrication, this kind of lubrication does not require motion of one surface relative to another (applicable when velocities are small or zero, where the frictional resistance is absolute zero).

Elastohydrodynamic lubrication is the phenomenon that occurs when a lubricant is introduced between surfaces that are in rolling contact, such as mating gears or rolling bearings. (Uses Hertizian theory of contact stress and fluid mechanics).

A decrease in viscosity may due to:

- Insufficient area
- A drop in the velocity of the moving surface
- A lessening in the quantity of lubricant delivered to a bearing
- An increase in the bearing load
- An increase in lubricant temperature

This may prevent the buildup of a film thick enough for full-film lubrication, which results in boundary lubrication. The change from hydrodynamic to boundary is quite slow.

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When bearing must be operated at extreme temperature, a solid-film lubricant such as graphite or molybdenum disulfide must be used because the ordinary mineral oils are not satisfactory.

One important measure to ensure that conditions for appropriate lubrication regimes are met is through defining and calculating the dimensionless film parameter Λ, given the minimum film thickness (the method of calculating minimum film thickness is shown in the journal bearing section) and surface roughness of say plain bearing (refer to ISO 12129-2:1995). The equation to determine Λ (between shaft and bearing) is as follows :

$$\Lambda = \frac{h_{min}}{R_a + R_b}$$

- R_a = rms surface roughness of surface a
- R_b = rms surface roughness of surface b

The range of lubrication regime is defined as:

Hydrodynamic lubrication: $5 \leq \Lambda \leq 100$

Elastohydrodynamic lubrication: $3 \leq \Lambda \leq 10$

Partial lubrication: $1 \leq \Lambda \leq 5$

Boundary lubrication: $\Lambda < 1$

Lubrication in journal bearing

Journal bearings can operate in any of three lubrication regimes: thick-film lubrication, thin-film lubrication, or boundary lubrication. Generally thick-film operation is preferred. Table below illustrates characteristics of the lubrication regimes (Theo, 2004):

μ = dynamic viscosity, N = revolution per unit time, W = load, L= bearing width, D = diameter

Lubrication regime	Contact of bearing surfaces	Range of film thickness, in	Coefficient of friction	Degree of wear	Comment
Thick film	Only during start up or stopping	10^{-3}- 10^{-4}	0.01 – 0.005	None	Light-loading high-speed regime Friction coefficient proportional to μN/[W/(LD)]
Thin film	Intermittent; Dependent on surface roughness	10^{-4} to $0.5*10^{-4}$	0.005 – 0.05	Mild	High operating temperature
Boundary	Surface to surface	$0.5*10^{-4}$ to molecular thicknesses	0.05 – 0.15	Large	Heat generation and friction no dependent on lubricant viscosity

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Explanation of thick film lubrication relative to journal operating speed

At rest or at slow shaft speed, the journal will contact the lower face of the bearing. This condition is known as boundary lubrication, considerable wear can occur in this period. As shaft speed increase, oil dragged around by the shaft penetrates the gap between the shaft and the bearing so that the shaft begins to "float" on a film of oil. This is called thin film lubrication. The journal may occasionally contact the bearing particularly when shock load occurs. Moderate wear may occur at these times. At high speed, oil film thickness increases until there comes a point where the journal does not contact the bearing at all. This is known as thick lubrication and no wear/damage will occur at this point (Tafe, 2000).

One can show these events in terms of a graph (shown below):

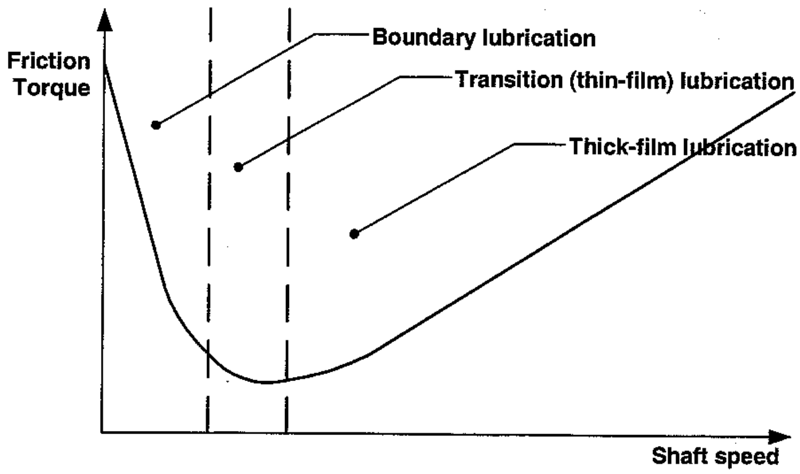

Figure 3 Frictional torque versus speed

The most desirable region is around the onset of thick film lubrication. Below this point, wear occurs, above this point, friction torque is high.

A general guide to bearing performance can be obtained by calculating the bearing modulus *M,* which is defined as:

$$M = \frac{\mu v}{\rho}$$

Where: μ = dynamic viscosity of the lubricant (centipoise cp) at the operating temperature of the bearing
v = linear velocity of the journal (m/s)
p = bearing pressure calculated on the *projected* area (MPa)

Note : 1 cp = 1000 Pa s

A design thumb of rule is that the onset of thick film lubrication occurs at a bearing modulus of 75 (Tafe, 2000).

Oil lubrication

Oils are used in journal bearings when cooling is required (or when debris need to be flushed away from bearing). High speed journal bearing are always lubricated with oil rather than grease.

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Viscosity for journal bearing can range between 20 – 1500 cSt (Lansdown, 2004). Viscosity grade is dependent upon bearing RPM (of shaft), oil temperature and load. The following table provides a general guideline in selecting the correct ISO viscosity grade (Noria, 2005).

Bearing Speed	Bearing / Oil Temperature (°C)			
(rpm)	0 to 50	60	75	90
300 to 1,500	-	68	100 to 150	-
~1,800	32	32 to 46	68 to 100	100
~3,600	32	32	46 to 68	68 to 100
~10,000	32	32	32	32 to 46

ISO VISCOSITY GRADE (ISO VG)	KINEMATIC VISCOSITY AT 40°C (mm^2/s)		
	Minimum	Maximum	Mid-point
2	1.98	2.42	2.20
3	2.88	3.52	3.20
5	4.14	5.06	4.60
7	6.12	7.48	6.80
10	9.0	11.0	10.0
15	13.5	16.5	15.0
22	19.8	24.2	22.0
32	28.8	35.2	32.0
46	41.4	50.6	46.0
68	61.2	74.8	68.0
100	90.0	110	100
150	135	165	150
220	198	242	220
320	288	352	320
460	414	506	460
680	612	748	680
1000	900	1100	1000
1500	1350	1650	1500

The ISO grade number indicated is the preferred grade for speed and temperature range. ISO 68- and 100-grade oils are commonly used in indoor, heated applications, with 32-grade oils being used for high-speed (10,000 RPM) units and some outdoor low-temperature applications. Note in the table that the higher the bearing speed, the lower the oil viscosity required; and that the higher the operating temperature of the unit, the higher the oil viscosity that is required. If vibration or minor shock loading is possible, a higher grade of oil than the one indicated in Table 1 should be considered.

Another method of determining the proper viscosity grade is by applying minimum and optimum viscosity criteria to a viscosity to temperature plot. A generally accepted minimum viscosity of the oil at the operating temperature for journal bearing is 13 cSt (CentiStokes), although some designs allow for an oil as thin as 7 or 8 cSt at the operating temperature. The optimum viscosity at the operating temperature is 22 – 35 cSt, for moderate speed bearings if no shock loading occurs. The optimum

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Fax: +61 8 9457 8642
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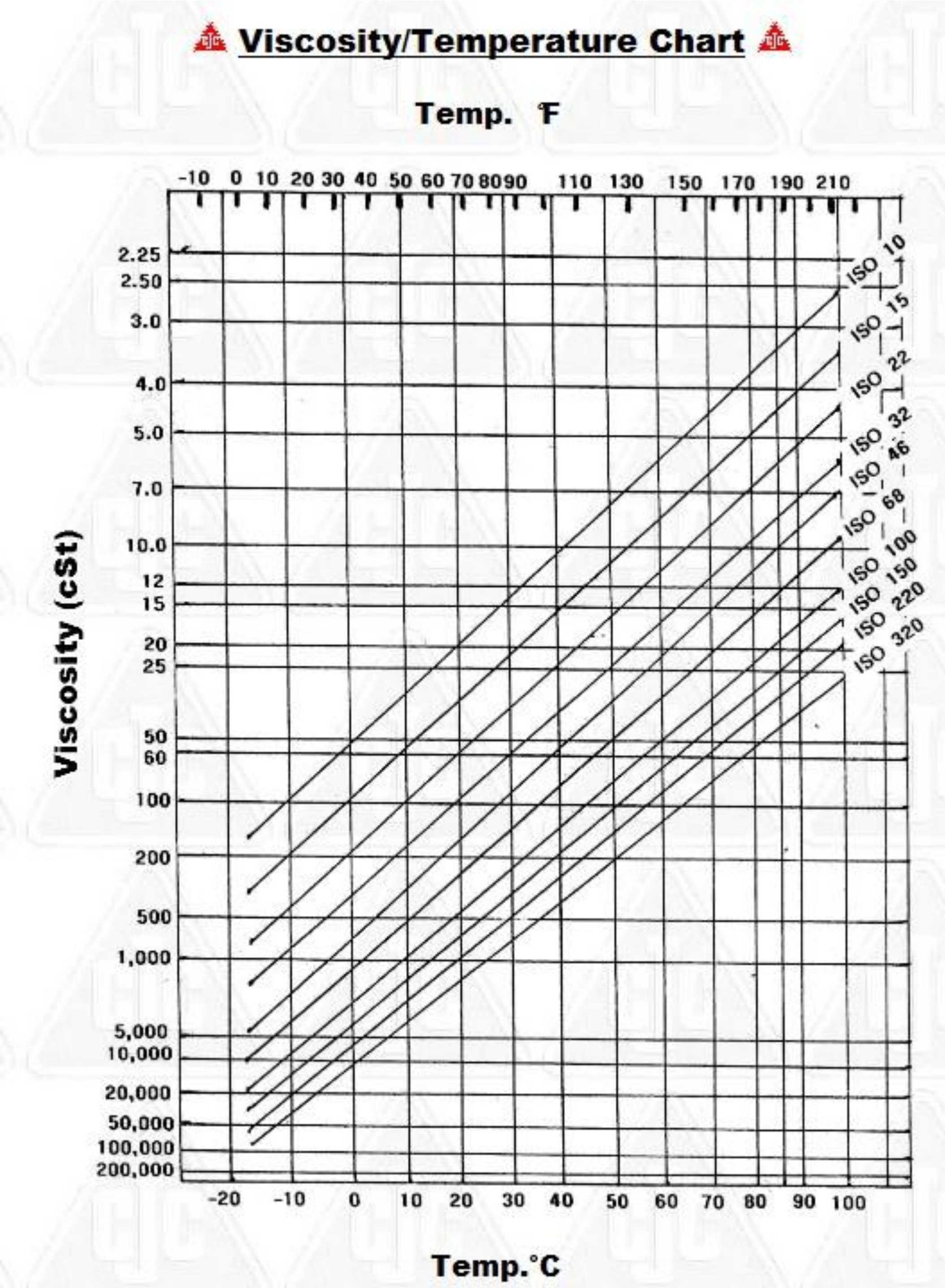
viscosity maybe as high as 95 cSt for low speed, heavy loaded or shock loaded journal bearings. An example of the chart is shown below (Klassen Specialty Hydraulics, 2003):



Using the above method requires some knowledge of the oil temperature within the bearing under operating condition. It is common to determine the temperature of the outer surface of the pipes carrying oil to and away from the bearing. The temperature of the oil inside of the pipes will generally be higher (5 to 10°C, 10 to 18°F) than the outer metal surface of the pipe. The oil temperature within the bearing can be taken as the average of the oil entering versus the temperature exiting the bearing.

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A third and more complex method is to calculate the oil viscosity needed to obtain a satisfactory oil film thickness. This method is demonstrated in the database (refer to journal bearing section).

It is important to the keep viscosity of the oil within the desired range. If it is too low, heat will be generated due to insufficient film thickness and some metal to metal contact will occur. If it is too high, heat will again be generated, but due to the internal fluid friction created within the oil. High viscosity can also increase likelihood of cavitations.

In terms of additives, a rust and oxidation (R&O) inhibited system is used in the oils. Antifoam and pour point depressant additives may also be present. Antiwear (AW) hydraulic oils may also be used as long as the high-temperature limit of the zinc AW component is not exceeded and excessive water is not present. R&O oils tend to have better water separation characteristics, which is beneficial, and the AW properties of a hydraulic oil would be beneficial only during startup and shutdown, assuming a properly operating bearing.

Viscosity in oil is also affected by the soot content and level of oxidation, which could have implications for oil film thicknesses and pumping losses. The soot and particulate contents have a major effect on wear of the cast iron flat and less of an effect on the ring for the materials studied here. Although the particulate content is important, it is a difficult quantity to measure using optical particle counting techniques in used oil (Truhan, Qu, & Blau, 2005).

A typical lubricant specification requirement is shown by the table below (Lansdown, 2004):

Test	*Limits*	*Method*
Viscosity, kinematic:		
cSt at 40 °C	60-75	IP71/97*
cSt at 100 °C	8.3-8.5	IP71/97
Flash point, closed cup (°C)	Min. 190	IP34/99
Pour point (°C)	Max. −10	IP15/95
Total acid number (mg KOH/g)	Max. 0.1	IP177/96
Copper corrosion, classification	Max. 1	IP154/2000

* The second number indicates the date of most recent revision. This date can often be omitted in general use, but in specifications it should always be quoted.

Regarding the lubricant standards: you can refer to BS4475 – a specification for straight mineral lubricating oil. BS4231 – classification for viscosity grade of industrial liquid lubricants or guides to recommended practice. (These need to be purchased through website if you think it is necessary, please let me know). It is highly recommended for you to read through the text book: ***lubrication and lubricant selection*** *for additional information*, this is included in the zipped file.

Grease lubrication

Grease is used to lubricate journal bearings when cooling of the bearing is not a factor, typically if the bearing operates at relatively low speeds. Grease is also beneficial if shock loading occurs or if the bearing frequently starts and stops or reverses direction. Grease is almost always used to lubricate pins

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and bushings because it provides a thicker lubricant than oil to support static loads and to protect against vibration and shock-loading that are common in many of these applications. A table illustrating composition of the grease is listed below (Lansdown, 2004):

Base oils	*Thickeners*	*Additives*
Mineral oils	Sodium soap	Anti-oxidants
Synthetic hydrocarbons	Calcium soap	Anti-wear additives
Di-esters	Lithium soap	EP additives
Silicones	Aluminium soap	Corrosion inhibitors
Phosphate esters	Lithium complex	Molybdenum disulphide
Perfluoropolyethers	Calcium complex	Friction modifiers
Fluorinated silicones	Aluminium complex	Metal deactivators
Chlorinated silicones	Bentonite clay	VI improvers
Polyglycols	Silica	Pour-point depressants
	Carbon/graphite	Tackiness additives
	Polyurea	Water repellants
	PTFE	Dyes
	Polyethylene	Structure modifiers
	Indanthrene dye	
	Phthalocyanine dye	

Lithium soap or lithium complex thickeners are the most common thickeners used in greases and are excellent for most journal bearing applications. Greases are classified by their stiffness or consistency (relative hardness or softness) (the most important property of grease) according to NLGI (US national lubricating grease institute). These classifications are based on the degree of penetration achieved when a standard cone is allowed to sink into the grease at a temperature of 77°F (25°C) for a period of five seconds.

Consistency is assessed by measuring the distance in tenths of a millimeter to which a standard metal cone penetrates the grease under a standard load; the result is known as the penetration (NLGI classification).

NLGI number	Worked penetration at 25°C
000	445–475
00	400–430
0	355–385
1	310–340
2	265–295
3	220–250
4	175–205
5	130–160
6	85–115

The consistency of grease varies with temperature, and there is generally an irregular increase in penetration (softening) as the temperature increases. Eventually a temperature is reached at which the grease is soft enough for a drop to fall away or flow from the bulk of the grease; this is called the drop point. The drop point is usually taken to be the maximum temperature at which the grease can be used in service.

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Grease; type of limit	Life, h				
	1	10	10^2	10^3	10^4
Synthetic greases; oxidation limit with unlimited oxygen present	275 to 285	255 to 265	225 to 240	200 to 225	175 to 200
Synthetic greases; drop-point limit with inorganic thickeners	250	250	250	250	250
Mineral-oil greases; upper limit imposed by drop point depends on thickener; oxidation dependent on amount of oxygen present	80 to 200	80 to 200	80 to 200	80 to 200	80 to 200
Mineral greases; oxidation limit with unlimited oxygen	185 to 200	160 to 175	135 to 150	110 to 125	85 to 100
Mineral greases; lower limit imposed by high torque	−50 to −10	−50 to −10	−50 to −10	−50 to −10	−50 to −10
Synthetic greases; lowest limit imposed by high torque	−70 to −80	−70 to −80	−70 to −80	−70 to −80	−70 to −80

Table: temperature limits in Degrees Celsius for greases as function of required life

The grade of grease used is typically an NLGI grade #2 with a base oil viscosity of approximately 150 to 220 cSt at 40°C (also refer to document: Viscosity classification for grease grade). Greases for low-speed, high-load, high temperatures and for pins and bushings may use a higher viscosity base oil and be formulated with EP and solid additives. Greases for improved water resistance may be formulated with heavier base oils, different thickeners and special additive formulations. Greases for better low-temperature dispensing may incorporate a lower viscosity base oil manufactured to an NLGI #1 specification. Bearings lubricated by a centralized grease dispensing systems typically use a #1, 0 or 00 grade of grease.

The apparent viscosity of grease changes with shear (pressure, load and speed) that is, greases are non-Newtonian or thixotropic. Within a rotating journal bearing, as the bearing rotates faster (shear rate increases), the apparent viscosity of the grease decreases and approaches the viscosity of the base oil used in grease. At both ends of the bearing shell, the pressure is lower and therefore the apparent viscosity remains higher. The resulting thicker grease at the bearing ends acts as a built-in seal to reduce the ingression of contaminants.

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(Shigley, 2004)

Lubricating greases are not simply very viscous oils. They consist of lubricating oils, often of quite low viscosity, which have been thickened by means of finely dispersed solids called thickeners. The effect of the thickeners is to produce a semi rigid structure in which the dispersion of thickener particles is stabilized by electric charges. The liquid phase is firmly held by a combination of opposite electric charges, adsorption, and mechanical trapping. As a result, the whole grease behaves as a more or less soft solid, and there is only a very slight tendency for the oil to flow out of the grease.

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The table below lists the range of temperature limits in Celsius for some synthetic oil as a function of the required life:

Name of lubricant; type of limit	Life, h				
	1	10	10^2	10^3	10^4
Polyphenyl ethers; thermal stability limit	545	520	490	455	425
Polyphenyl ethers; oxidation limit	350	330	305	280	260
Silicones; thermal stability limit	280 to 290	260 to 275	240 to 260	220 to 245	200 to 230
Esters and silicones; oxidation limit	225 to 260	215 to 245	200 to 240	185 to 220	175 to 210
Phosphate esters; thermal and oxidative limit	160	145	130	110	100
Polyphenal ethers; pour-point limit	0	0	0	0	0
Silicones and esters; pour-point limit	−60	−60	−60	−60	−60

The next table lists some compatible and incompatible materials for different oil types:

Oil type	Rubbers and plastics	
	Satisfactory	Unsatisfactory
1. Natural oils	Most rubbers, including natural rubber; most plastics	SBR rubber; highly plasticized polyethylene and polypropylene
2. Mineral oil	Nitrile rubber; neofrene; Viton; EPR; most unplasticized plastics	Natural rubber; SBR; highly plasticized plastics; polyurethanes
3. Esters	High nitrile; Viton; nylons; PPS; polyethersulfones	Natural rubber; SBR; low nitrile; polyacrylates; polyurethanes
4. Silicones	High nitrile; Viton; nylons; PPS	Natural rubber; silicone rubber; plasticized plastics
5. Phosphate ester	Resin-cured butyl rubber; EPR; PPS	Most other rubbers; many plastics

The selection of grease for a specific application depends on five factors: speed, load, size, temperature range, and any grease feed system. For average conditions of speed, load, and size with no feed system, NLGI no. 2 grease would be the normal choice, and such grease with a mineral-oil base is sometimes known as multipurpose grease.

1. Speed - For high speeds, stiffer grease, NLGI no. 3, should be used except in plain bearings, where no. 2 would usually be hard enough. For lower speeds, softer grease such as no. 1 or no. 0 should be used.

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2. Load - For high loads, it may be advantageous to use EP additives or molybdenum disulfide. Because higher loads will lead to higher power consumption and therefore higher temperature, a stiffer grease such as no. 3 or a synthetic-base oil may help.
3. Size - For large systems, use a stiffer grease, no. 3 or no. 4. For very small systems, use softer grease, such as no. 1 or no. 0.
4. Temperature range - The drop point should be higher than the maximum predicted operating temperature. For sustained operation at higher temperatures, synthetic-base oil may be necessary. For very high temperatures, about 230°C, one of the very expensive fluorocarbon greases may be required.
5. Feed systems - If the grease is to be supplied through a centralized system, usually it is desirable to use one grade softer than would otherwise be chosen (i.e., use a no. 0 instead of a no. 1 or a no. 00 instead of a no. 0). Occasionally a particular grease will be found unsuitable for a centralized feed because separation occurs and the lines become plugged with thickener, but this problem is now becoming less common.

Objective of lubricating oil

The primary function of lubricating oil is to separate surfaces, reduce friction and absorb heat. Secondary responsibilities include regulating temperature, flushing contaminants, controlling corrosion and providing hydromechanical performance. Improper lubricating oil type, contaminated oil, poor equipment operation, poor maintenance or poor component manufacturing reduce the ability of the lubricating oil to function. These factors can disrupt the hydrodynamic or elastohydrodynamic (EHD) lubrication film between the metal surfaces leading to premature wear of the metal surfaces and high overall operating costs.

When metal-to-metal or particle-to-metal contact exists because of a loss or interference in the lubricating film, adhesive and abrasive wear occurs. This generates more friction, heat and wear particles that further contaminate the oil. Even under ideal conditions of manufacturing, operation and maintenance, other contaminants, such as dirt and moisture, can get into lubricating oil. If dirt or silica particles are large enough they can cause interferences between metal contact surfaces. Moisture, on the other hand, breaks down viscosity and alters the chemical properties of the oil (Weiksner, 2000).

Analysis of lubricating oil will identify the source of a contaminant, whether the chemical properties of the oil are intact and if machine wear is occurring. It is important to be able to relate results of a lubrication analysis to the oil chemical properties, the various types of metals used in manufacturing the rotating elements, and the operating conditions of a machine. Controlling oil cleanliness minimizes the effects solid particle contamination can have on interfering with the lubricating oil film. It also maintains separation of the metal surfaces.

When the size of the particulate is greater than the clearance between metal rotating surfaces, abrasion and fretting of the metal surfaces occurs. Once abrasion or fretting starts, the lubricant functions are adversely affected and additional surface damage will result. The continuous contact between particulate and metal generates additional wear debris and larger particulate. To quantify the amount and size of solid particulate contamination in oil, **ISO 4406:1999** was developed, shown in table below:

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Particles per mL		
More than	Up to and including	Scale number (R)
160,000	320,000	25
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7

Table 1: allocation of scale numbers (Weiksner, 2000)

The standard provides the method for coding oil cleanliness based on the solid particulate micron size and the amount of that size particulate present in the oil. Oil cleanliness standards established by ISO in 1999 correlate to the identification of solid particulate measuring 4, 6 and 14 microns in size (represented as R4/R6/R14) according to the quantity of these solid particles found per each milliliter of oil.

The ISO particulate size classification $R_4/R_6/R_{14}$ can be compared to tolerances (fits) or clearances between machined components. Table below provides the typical clearances in microns for various shaft size and shaft/housing combinations and for various machine fit classifications.

Shaft Size (inches)	Class 1 (RC8-Loose)	Class 2 (RC7-Free)	Class 3 (RC5/RC6-Medium)	Class 4 (RC4-Snug)
1	63 to 191	35 to 102	22 to 64	0 to 25
1.5	83 to 228	45 to 122	30 to 76	0 to 30
2	101 to 260	55 to 142	35 to 86	0 to 32
3	132 to 315	73 to 170	48 to 124	0 to 37
6	211 to 439	117 to 239	76 to 150	0 to 45

Table 2: class of fit, micron clearances; (Most industrial equipments belong to class 2 or 3) (Weiksner, 2000)

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The table below provides normal static unmounted manufacturer internal clearances for a typical deep groove ball bearing and a polyoxymethylene (POM) composite journal bearing for the same shaft sizes as shown in the table above.

Bearing Size (inches)	Deep Groove Ball Bearings (microns) [3]	POM Journal Bearings (microns) [4]
1	5 to 20	50 to 164
1.5	6 to 20	50 to 174
2	8 to 28	80 to 239
3	10 to 30	100 to 306
6	18 to 53	100 to 333

Table 3: bearing component micro clearances (Weiksner, 2000)

Whilst it appears that both tables above provides sufficient separation of metal surfaces for particles in $R_4/R_6/R_{14}$ size classification, when rolling element bearings are installed properly, the clearance is reduced to approximately half the values listed in table 3 above.

For example, a one-inch rolling element bearing installed on a Class 2 or Class 3 machined one-inch shaft will have an operating or running clearance between 2.5 and 10 microns when installed properly. If the installed one-inch bearing is lubricated with oil containing solid contamination of any source that is equal to or greater than 2.5 microns, abrasive or fretting wear may occur.

An operating or running clearance would typically be between these values except for the highly loaded areas of the rotating components. A significant amount of particulate contamination in lubricating oil that is greater than the clearance between contact surfaces will generate noise and vibration, and raise operating temperature due to the heat caused by increased friction. It is therefore important to have good maintenance, good operating practices, trained mechanics and oil free of solid particulate contamination.

Cleanliness code

These cleanliness code standards should be used for both new oil shipped to the site and for establishing contamination alarm levels on machines. The allowable level of particulate for each of the cleanliness codes is quantified according to Table 1 (above).

Periodic oil samples should be taken to determine if the oil particulate is within or below these cleanliness levels. Anytime the level of particulate concentration exceeds the established cleanliness code, the oil should be filtered to remove contaminants or changed. Removing particulate contamination will prevent surface wear, increase machine reliability and prolong the life of the rotating elements. If contamination is found in new oil, the oil should be returned to the supplier. Table 4 below shows typical machines or equipment at SRS (Savannah River Site case study) where the various ISO viscosity grade oils are used.

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ISO Viscosity Grade Classification	Machine or Equipment Description
32	Hydraulics, lightly loaded slideways
46	Hydraulics, rotary screw compressors
68	Vertical motors, turbines, journal bearings, pumps
100	Reciprocating air compressors, angle drives, conveyors
150	Gear reducers, screw conveyors, feeders
220	Turbine drives, cooling tower drives, heavily loaded slideways
320	Gear reducers
460	Exhausters, vacuum pumps, large conveyor drives
680	Gear drives

Table 4 (Weiksner, 2000)

Table 5 provides the recommended cleanliness code based on the viscosity grade:

ISO Oil Grade Classification	Cleanliness Code ($R_4/R_6/R_{14}$)
32	16/14/11
46	16/14/11
68	17/14/12
100	18/15/13
150	18/15/13
220	19/16/14
320	19/16/14
460	19/16/14
680	20/18/14

Table 5 (Weiksner, 2000)

The cleanliness code can be explained as follow: e.g. 16/14/11 means there are 320 – 640 particles larger than 4 micron per milliliter sample. Also there are between 80 – 160 particles larger than 6 micron per milliliter sample and between 10 – 20 particles larger than 14 micron per milliliter sample.

Manufacturers often provide guidelines for ISO grade of the lubricating oil based on standard operating condition. An example of manufacturers' specification is included in document: Understanding ISO Codes (attached).

There are also companies which specialize in analyzing the cleanliness of the oil. An example of the equipment is included in document: portable oil diagnostic system.

Other resources: Caterpillar uses ISO 16/13 , other use 17/14, note that sometimes oil needs to be filtered to bring down to a much lower solid level, up to 14/13 (Oil transfer systems, 2008).

Journal bearing (high speed) 17/15/12

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Journal bearing (low speed) 17/15/12

Roller bearing 16/14/12 (Whitefield, 1999)

Dave suggested typical "new" turbine oils, crankcase oils, hydraulic oils and bearing oils can range from as low as 14/11 to as high as 23/20.

- ISO 14/12/10 - NAS 4: Very clean oil, best for all oil systems.
- ISO 16/14/11 - NAS 5: Clean oil, an absolute necessity for servo & high pressure hydraulics.
- ISO 17/15/12 - NAS 6: Light contaminated oil, standard hydraulic and lube oil systems.
- ISO 19/17/14 - NAS 8: New oil, for medium to low pressure systems.
- ISO 22/20/17 - NAS 12: Very contaminated oil, not suitable for oil systems

http://www.triple-r-europe.com/index.php?option=com_content&view=article&id=76&Itemid=122&lang=

(Due to its condition an oil sample has to be counted in some cases using a light microscope. In that case a **2-digit-code** is used only. This code belongs to all particles > 5µm and >15µm)

ISO code compliance

High ISO Cleanliness codes indicate high levels of particulate contamination in the oil, which increase wear and shorten the lives of both machinery and lubricants. However, if a company maintains a sophisticated and effective contamination control program, the codes can be used to achieve increased efficiency and reduced downtime.

The codes are also used as a basis for comparison, to understand how equipment performs under specific cleanliness levels. Maintenance personnel typically use the codes to evaluate the need for various levels of contamination protection.

ISO Cleanliness codes themselves do not differ for various components. There are no set standards outside a handful of original equipment manufacturer recommendations, but Table below provides a fluid cleanliness guide for hydraulic systems.

Operating Pressure →	<1,500 psi	1,500-2,500 psi	>2,500 psi
Servo Valve	16/14/12	15/13/11	14/12/10
Proportional Valve	17/15/12	16/14/12	15/13/11
Variable Volume Pump	17/16/13	17/15/12	16/14/12
Cartridge Valve	18/16/14	17/16/13	17/15/12
Fixed Piston Pump	18/16/14	17/16/13	17/15/12
Vane Pump	19/17/14	18/16/14	17/16/13
Pressure/Flow Control Valve	19/17/14	18/16/14	17/16/13
Solenoid Valve	19/17/14	18/16/14	18/16/14
Gear Pump	19/17/14	18/16/14	18/16/14

Adjust to cleaner levels for duty cycle severity, machine criticality, fluid type (water base) and safety concerns.

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Fax: +61 8 9457 8642
Email: info@lifetime-reliability.com
Website: www.lifetime-reliability.com

In addition to the table presented above, please also see:

http://www.boschrexroth.com/business_units/brm/sub_websites/eppensteiner/en/products/know-how/recommended_oil_cleanliness_codes/index.jsp

And also oil cleanliness guideline (as attached).

Generally, the tighter the tolerance on the component's metal-to-metal surfaces, the tighter the cleanliness code. For instance, servo valves on hydraulic systems are more susceptible to contamination-related failures than low-speed gearboxes. Therefore, the hydraulic reservoir fluid will require a lower ISO code (cleaner fluid) than the gearbox. This knowledge allows maintenance departments to focus on preventing failures instead of treating them, and prompts them to employ enhanced tactics to keep contamination out of the hydraulic reservoir (Leonard, 2005).

Also refer to document: Understanding ISO codes pdf attached.

Contaminants in oil

Any oil contaminated and the majority of hydraulic and lubrication problems are attributable to contaminants. Whilst standards based on particle counts (e.g. ISO 4406, NAS 1638) are fully developed, not enough attention has been paid to varnish or polymerized oil oxidation products of molecular size (this is partially due to the lack of study on specification of contaminants in oils). To effectively solve the problem of lubricating oil, it is imperative to identify what contaminants are really harmful to hydraulic and lubricating system and how they are produced (Sasaki, 2005).

By using methods of dilution, washing and oxidation (solvent extraction method), the study shows the oil contaminants consist of:

- Oil oxidation products
- Decomposed material of oil additives
- Worn metals and dusts

It shows that oil oxidation products are the most abundant of the three. It is found to be soluble in toluene. The oil oxidation products are particularly damaging, as they are polar and are absorbed on metal surface, which have permanent dipole moment, to build up deposit. Polymerized oil oxidation product cause high friction which lead to lubrication problems.

Other characteristics of oil

The single most important property of lubricant oil is its viscosity. It often directly relates to the requirements of the operating equipment (e.g. pump) and condition. Other important characteristic the lubricating oils are (Chevron, 2008):

- Oxidation stability (or oxidation products): enable operation of the oil during long period of time
- Rust Prevention: Protects vital system parts against corrosion in the presence of water
- Demulsibility: Rapidly separates any water from the oil
- Antiwear: Provides adequate lubrication of moving parts, even under boundary lubrication conditions
- Air Release: Readily releases entrained air

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- Antifoam: Prevents buildup of a stable foam layer, especially in the reservoir
- Low Pour Point: Permits low temperature operations
- High Viscosity Index: Minimizes viscosity changes with temperature and allows a wider operating temperature range

The table below illustrates the acceptable warning limit for contamination levels

Filter residue (using 0.8-micron membrane filters)	
0 to 50 mg/kg	Oil is clean
50 to 150 mg/kg	Oil is generally acceptable
150 to 300 mg/kg	Oil is suspect; filters need to be changed; monitoring recommended
300 to 400 mg/kg	Oil is heavily contaminated and should be severely filtered
Above 400 mg/kg	Oil is heavily contaminated and should be replaced
High-pressure system (above 70 bar) limits	
0 to 30 mg/kg	Oil is clean
30 to 100 mg/kg	Oil is suspect; filters should be changed; monitoring recommended
Above 100 mg/kg	Particulate matter content is too high. Oil should be changed unless the amount of particulate matter can be rapidly reduced by filtration.

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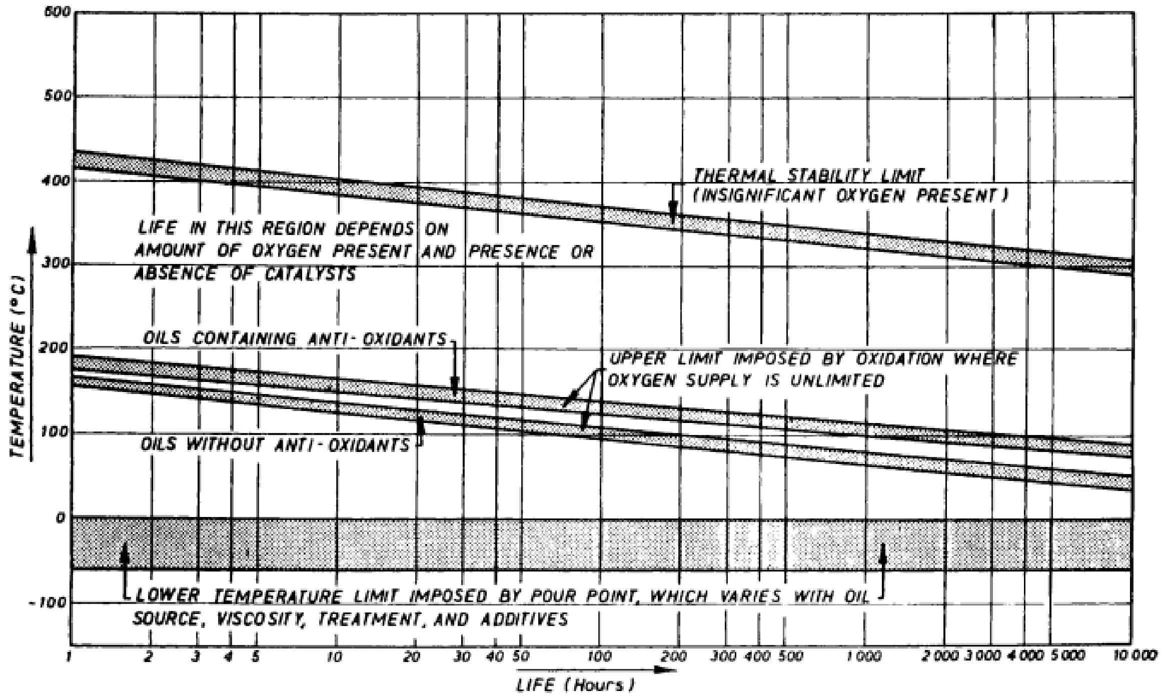

In general, there are many different possible contaminants, including (Lansdown, 2004):

- Water from condensation or combustion
- Unburned fuel in an engine
- Wear debris
- Dust from atmosphere
- Process liquids
- Chemicals in chemical plant
- Break down of product from base oil
- Corrosion products
- Breakdown products of additives

Not all contaminants are undesirable in themselves, but any of them can cause further deterioration and more contamination and two or more of them may act together to cause more damage than they would separately. Examples of these include:

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- Dust, corrosion products and wear debris can increase wear and thus produce more wear debris
- Acidic breakdown products and water can produce a corrosive mixture and thus generate more corrosion products
- Acidic breakdown products and water can form a surface active mixture which will emulsify with the oil and block feed holes and filters
- The same emulsion makes an ideal medium for microbiological growth (bacteria and fungi) which feed on the oil itself
- Soot and the debris from microbiological growth can block feed pipes and filters

Contamination prevention and removal

The best quality of lubricating oil can be assured by using various techniques coping with contamination problems:

Controlling entry of contaminants: eliminates contaminants such as air dust and moisture, chemical and process liquid can be reduced or even eliminated by efficient sealing or filtration of air supplies

Removal of contaminants: filtration will remove solid particles, centrifuge will remove liquid particles.

Dispersing contaminants: certain solid contaminants, such as soot and oil breakdown products, tend to accumulate and block oil ways or filters. Dispersant and detergent additives are used to keep the particles dispersed.

Neutralization: acid products from oil breakdown or from burning of sulphur containing fuel maybe neutralized by basic additives such as calcium compounds in order to prevent corrosion.

There are numerous methods available to meet the appropriate cleanliness codes, which vary according to equipment and environment. The main objective is to stop contamination from initial entry, because studies show that it is approximately ten times more cost-efficient to prevent contamination than it is to remove it once it is present in a system. Specific solutions include quality breathers, hydraulic sleeves and improved storage and handling of fluids.

Several technologies exist for the removal of solid contaminants from a lubrication system. The most widely used method is filtration, followed by centrifuge and electrostatic technologies.

It is also important to institute a contamination control program for the establishment and monitoring of appropriate target cleanliness codes for machinery, storage and dispensing of lubricants, periodic cleaning of reservoir tanks and storage vessels, and installation of breathers to reduce ingression of contaminants. Oil analysis can be used for tracking trends to determine the value of various preventive maintenance efforts.

Some of the major lubricant manufacturers offer programs to help control fluid contamination and maximize lubricant investment values. For instance, ChevronTexaco's IsoClean™ Solutions offers fluid conditioning services to remove damaging particulates from system fluids and IsoClean™ storage containers to provide fluid contaminant protection and improve facility and system cleanliness. Desiccant breathers created by Des-Case® Corporation reduce airborne particulate and water contamination, which are leading causes of lubricant-related equipment failure. Petrolink USA, Inc.,

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Fax: +61 8 9457 8642
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offers on-site lubricant reconditioning and preventive maintenance services to manufacturing facilities in the Midwest, Northeast and Southeastern areas of the United States.

Benefit derived from maintaining high cleanliness of oil

There are many cases where compliance with a higher standard of cleanliness has significantly improved operations at industrial facilities. For instance, the authors assisted a leading national independent petroleum refiner to institute all-inclusive contamination control programs. The petroleum refiner has significantly reduced lubricant spending along with upgrading its products to Group II and synthetics. They have experienced fewer maintenance failures over the last three years, along with significantly reducing lubricant purchases.

A major Midwest power plant realized a lubricants cost savings of 53 percent over a five-year period through better housekeeping measures and improved filtration, which included the use of desiccant breathers. After several months of practicing these improved processes, oil analysis reports showed a substantial decrease in silicon levels. The ISO level set for new oil supplied was 18/17/14. When the first in-service sample was taken, readings were 15/14/12, indicating that the oil was cleaner than when it came in the door. By consistently maintaining levels below code, the plant has achieved a four-fold extension of lubricant life. The same oil has been in service since October 2002 and based on sampling trends and sustainable cleanliness codes, plant technicians are expecting to extend its life to as much as five to seven years (Leonard, 2005).

Several years ago, Petrolink worked with a major wheel hub manufacturing facility in the Midwest who was experiencing large numbers of pump, valve and cylinder failures. The contamination levels in most of the systems were significantly higher than established targets and the maintenance department was primarily focused on repairing failed equipment.

The company implemented its preventive maintenance service program at the customer plant, which involved analysis, reservoir cleaning, fluid reclamation, filtration upgrades and system flushing. The results were staggering: In the first year, the plant reduced component usage and failures and unscheduled downtime by 60 percent, allowing maintenance staff to concentrate on proactive maintenance activities versus reactive. This resulted in bottom-line savings of $450,000 (Leonard, 2005).

These case studies help underline the huge savings and increased efficiency that industrial facilities can achieve through reliability-based maintenance programs that effectively monitor system cleanliness and remove contaminants. By implementing these programs, combined with the effective utilization of ISO Cleanliness codes as part of an efficient contamination control plan, increased efficiency and reduced downtime can be achieved. This means significant benefits for a company's bottom line and enduring success in today's highly competitive global economy (Leonard, 2005).

Nash (1998) claimed the extra effort and expense in caring for hydraulic fluid will return benefit for years. The amount of maintenance necessary for oil related problems can be reduced by 70 – 85. Additional benefits include (Nash, 1998):

- Saving of 70% on oil costs
- Reduction in overall equipment downtime caused by maintenance problems by over 50%
- Decrease in cost of power required to operate equipment

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- Maintenance of cycle times of new production equipments

Nash (1998) suggested the best procedure for ensuring that excessive contaimination is not being introduced into the hydraulic system at run up, is to maintain the fill oil at 13/10.

However, studies performed in many industries all show dramatic extensions in expected machinery life by improving lubricant cleanliness. In one example, a reduction of particles larger than 10 µm from 1000/mL to 100/mL resulted in a 5-fold increase in machine life… an attractive return on your cleanup investment. An additional benefit of cleaner oil is a lower noise floor for wear particle detection measurements. It’s much easier to detect subtle changes in the amount of wear debris in a clean system than in a dirty one (Whitefield, 1999).

Society of Automotive Engineers (SAE) studies have shown engine wear reductions of 50% when filtering crankcase oil to 30 µm, and 70% when filtering to 15 µm, as compared with filtering to 40 µm. (Whitefield, 1999)

The table below documents the life extension factors (Swan, 2006):

TABLE 3

	2x	3x	4x	5x	6x	7x	8x	9x	10x
26/23	23/21	22/19	21/18	20/17	20/17	19/16	19/15	18/15	18/15
25/22	23/19	21/18	20/17	19/16	19/15	18/15	18/14	17/14	17/14
24/21	21/18	20/17	19/16	19/15	18/14	17/14	17/13	16/13	16/13
23/20	20/17	19/16	18/15	17/14	17/13	16/13	16/12	15/12	
22/19	19/16	18/15	17/14	16/13	16/12	15/12	14/11		
21/18	18/15	17/14	16/13	15/12	15/11	13/10			
20/17	17/14	16/13	15/12	14/11	13/11				
19/16	16/13	15/12	14/11	13/10					
18/15	15/12	14/11	13/10						
17/14	14/11	13/10							
16/13	13/10								

Existing ISO cleanliness codes
Target ISO cleanliness codes
Life extension factor

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Basic class of lubricant

The table below summarizes the property of different lubricants (Lansdown, 2004):

Lubricant property	*Oil*	*Grease*	*Dry lubricant*	*Gas*
1. Hydrodynamic lubrication	Excellent	Fair	Nil	Good
2. Boundary lubrication	Poor to excellent	Good to excellent	Good to excellent	Usually poor
3. Cooling	Very good	Poor	Nil	Fair
4. Low friction	Fair to good	Fair	Poor to good	Excellent
5. Ease of feed to bearing	Good	Fair	Poor	Good
6. Ability to remain in bearing	Poor	Good	Very good	Very poor
7. Ability to seal out contaminant	Poor	Very good	Fair to good	Very poor
8. Protection against atmospheric corrosion	Fair to excellent	Good to excellent	Poor to fair	Poor to good
9. Temperature range	Fair to excellent	Good	Good to excellent	Excellent
10. Volatility	Very high to low	Generally low	Low	Very high
11. Flammability	Very high to very low	Generally low	Generally low	Unlimited variation
12. Compatibility	Very bad to good	Fair to good	Excellent	Generally good
13. Cost of lubricant	Low to very high	Fairly high to very high	Fairly high	Generally very low
14. Complexity of bearing design	Fairly low	Fairly low	Low to high	Very high
15. Life determined by	Deterioration and contamination	Deterioration	Wear	Ability to maintain gas supply

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The table below illustrates importance of lubricant properties with regard to different types of bearings (Lansdown, 2004):

	Type of bearing				
Lubricant property	*Plain journal*	*Rolling bearing*	*Closed gears*	*Open gears, ropes*	*Clock and instrument*
1. Boundary lubricating properties	*	*	***	***	**
2. Cooling	**	**	***		
3. Low friction	*	*	**	**	**
4. Ability to remain in bearing	*	**		***	***
5. Ability to seal out contaminants		**		**	
6. Temperature range	**	**	**	*	
7. Protection against corrosion	**	**	*	***	

*** Greatest importance; **less importance; *little importance;

Plain bearing lubricants: ideally, full fluid film lubrication is suggested as it gives complete separation of the journal bearing surfaces, so the friction is low and no wear takes place. If the speed is high, oil will be preferred, because it will give lower friction and can carry away the frictional heat. At lower speed, greases will be acceptable, because there will be no heating problems and the grease will be easier to retain in the bearing. If there is a problem of contamination by dust or dirt, grease will be better at sealing out the contaminants.

Some more plain bearing lubrication stuff

The following tables show methods of choosing the right lubricant, and principal additives and contaminants in lubricants (Neale, 2001):

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Lubricant	*Operating range*	*Remarks*
Mineral oils	All conditions of load and speed	Wide range of viscosities available. Potential corrosion problems with certain additive oils (e.g. extreme pressure) (see Table 7.9)
Synthetic oils	All conditions if suitable viscosity available	Good high and low temperature properties. Costly
Greases	Use restricted to operating speeds below 1 to 2 m/s	Good where sealing against dirt and moisture necessary and where motion is intermittent
Process fluids	Depends on properties of fluid	May be necessary to avoid contamination of food products, chemicals, etc. Special attention to design and selection of bearing materials

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Problem	*Occurs in*	*Requirements*
Oxidation of lubricant	IC engines Steam turbines Compressors High-speed gearboxes	Antioxidant additives
Scuffiing	Gearboxes Cam mechanisms	Extreme-pressure additive
Deposit formation	IC engines Compressors	Dispersant additives
Excessive wear of lubricated surfaces	General	Antiwear additives
Water contamination	IC engines Steam turbines Compressors	Good demulsification properties. Turbine-quality oils may be required
Dirt particle contamination	IC engines Industrial plant	Dispersant additives
Weak organic acid contamination	IC engines	Acid neutraliser
Strong mineral acid contamination	Diesel engines Process fluids	Acid neutraliser
Rusting	IC engines Turbines Industrial plant General	Rust inhibitor

The equation below shows a simple way of computing minimum viscosity required given the calculated surface speed, and mean pressure:

Plain journal bearings

Surface speed, $u = \pi d n$, ms^{-1}

Mean pressure, $\bar{p} = \frac{W}{ld}$, kNm^{-2}

where n = shaft speed, s^{-1}
l = bearing width, m
d = shaft diameter, m
W = load, kN

Minimum allowable viscosity $\eta_{min.}$, cP, may be read directly

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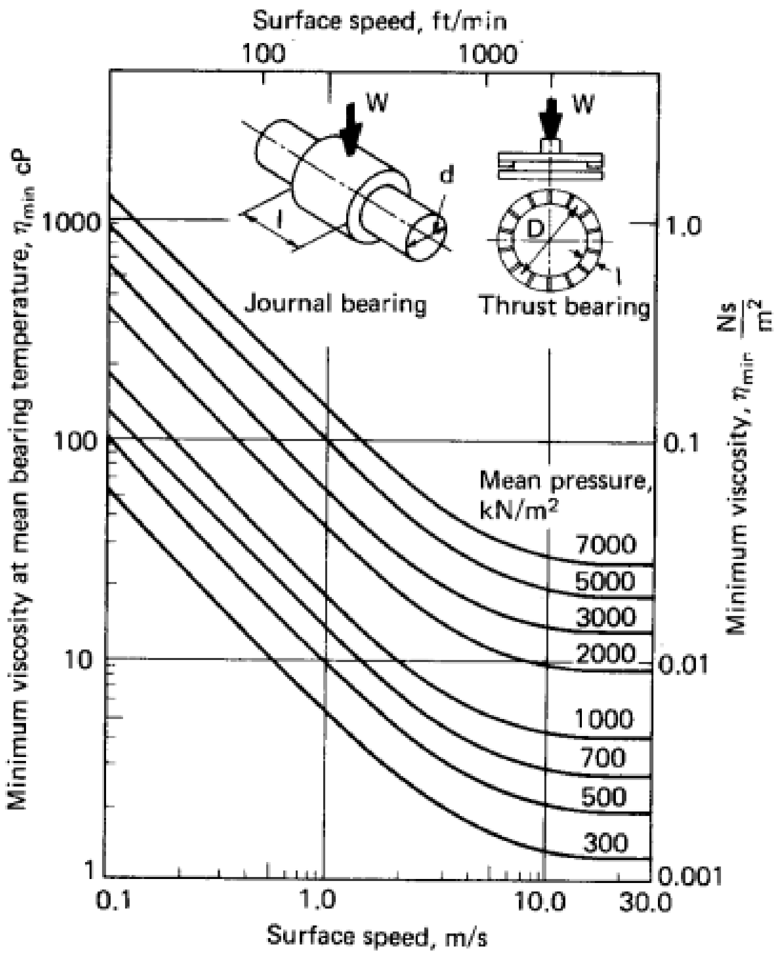

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