Moisture...the Second Most Destructive Lubricant Contaminant, and its Effects on Bearing Life

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This paper will discuss the influence of moisture on the chemical stability of a lubricant's additives and base stock, and the effects of moisture on machine surfaces (particularly wear and corrosion). Finally, a three-step, proactive maintenance strategy will be proposed to minimize the effects of moisture on lubricant and bearing life.

Moisture is generally referred to as a chemical contaminant when suspended in lubricating oils. Its destructive effects in bearings can reach or exceed that of particle contamination, depending on conditions. Like particles, control must be exercised to minimize water accumulation and damage to bearing surfaces.

Once water enters a machine with bearings (i.e., an engine, turbine, or gear box) it may move through several chemical and physical states. Water will often enter an oil in one of the five following ways:

Absorption - Oil is hygroscopic, meaning it can absorb moisture directly from the air. The amount of moisture that can be absorbed is influenced by the relative humidity of the air and the saturation point of water in the oil. Depending on temperature and pressure, this solubility will vary from about 100 ppm for a low additive oil to several thousand ppm for a high additive oil and certain synthetic oils. For any given water-in-oil saturation point and relative humidity, an equilibrium will be reached where the moisture moving from the air to the oil, and also from the oil to the air, is equal (Figure 1). Absorbed water is always dissolved in the oil at first, but later, due to temperature/pressure changes, may condense to a free or emulsified state.

Condensation - Humid air entering oil compartments will often cause moisture condensation on the walls and ceilings above the oil level. Frequent temperature change cycles may greatly increase the rate of condensation. Eventually the condensation will coalesce, flow down the walls, and form a layer of free water at the bottom of the tank.

Figure 1 -
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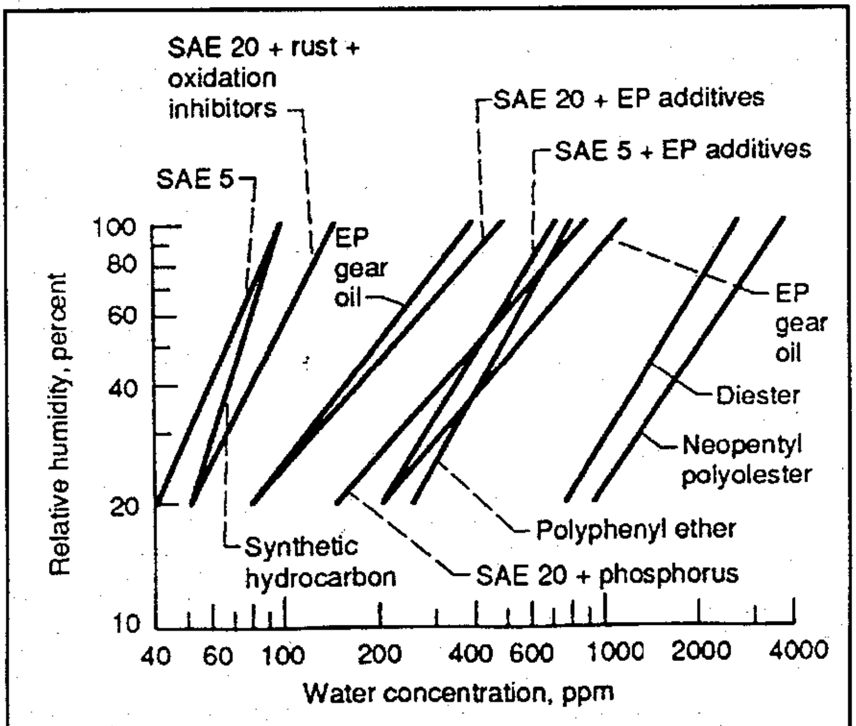


Heat Exchangers - Corroded or leaky heat exchangers are common sources of water contamination in lubricating fluids. In extreme cases, a rupture of the heat exchanger can cause massive amounts of water to enter the machine compartment.

Combustion/Oxidation/Neutralization - Fuel combustion in engines forms water in the exhaust gases as a by-product, which combines with water from induction air. Worn rings, liners and improper scavenging can allow water to enter the lube oil. Low jacket-water temperature and intermittent operation may prevent the water from vaporizing from the oil sump. Water can also be created in oil as a chemical by-product from certain types of corrosion and oxidation processes. In engine oils, water is also formed when alkalinity improvers neutralize acids formed during combustion.

Free Water Entry - During oil changes or the addition of makeup fluid, water can be introduced to oil sump. Condensation in storage containers is the most common origin of this water.

Water, once in an oil, is in constant search of a stable existence. Unlike oil, the water molecule is polar, which greatly limits its ability to dissolve; and many additives have polar extremities which can markedly increase water solubility. Water may cling to hydrophilic metal surfaces or form a thin film around polar solid contaminants such as silica particles. If a dry air boundary exists, water molecules may simply choose to migrate out of the oil to the far more absorbent air interface. This migration can be acclerated if air and oil mix, such as in splash lubricated and oil mist systems or any system where a stable fluid foam may exist.

If water molecules are unable to find polar compounds on which to attach, the oil is said to be saturated. Any additional water will create a supersaturated condition causing free water to be suspended or settle at the bottom of the sump. This supersaturation can also occur as a result of lower oil temperature.

When free water is suspended, a colloidal suspension or emulsion is said to exist, causing a visible cloud or haze in the oil. By lowering interfacial tension (below 25 dynes/cm), certain dispersant additives (engine oils) and emulsifying agents can permit water in oil emulsions in excess of 10% water. Typical low-additive industrial lubricants will hold no more than 0.5% water in an emulsified state. The higher shear rates associated with high speed systems can create microemulsions that inhibit coalescence and water settling.

Additives and Base Stocks

With few exceptions, the chemical and physical stability of lubricants are threatened by small amounts of suspended water. Water can promote chemical reactions (hydrolysis) with compounds including oil additives, base stock and suspended contaminants. In combination with oxygen, heat, and metal catalysts, water promotes the oxidation and the formation of free radicals and peroxide compounds. Oxidation inhibitors are sacrificed by neutralizing peroxides and oxidation chain reactions to form stable compounds. Other oxidation inhibitors form hydrogen sulfide and sulfonic acids when reacting with water. Experiments have shown the protection provided by zinc dialkyldithiophosphate (ZDDP), a common antiwear additive and antioxidant, can be destroyed by as little as one drop of water in a gallon of oil, if the oil temperature is above 180°F.

Water will also attack rust inhibitors, viscosity index improvers, and the oil's base stock, creating varnish, sludge, organic and inorganic acids, surface deposits and lubricant thickening (polymerization). Large amounts of emulsified water can lower viscosity, reducing a lubricant's load carrying ability. When water is combined with metal catalysts such as iron or copper, accelerated oil deterioration can occur. This results in base stock oxidation and the formation of free radicals (which continue the oxidation process), hydroperoxides, and acids (Figure 2).

Bearing Surfaces and Bearing Life

The harmful effects of water on the fatigue life of rolling element bearings is widely documented. According to SKF, "free water in lubricating oil decreases the life of rolling element bearings by ten to more than a hundred times..." Some of the damaging effects water causes include creating a corrosive environment and diminishing boundary layer and hydrodynamic protection.

The exact mechanisms by which water promotes bearing failure are not fully understood. There is evidence that water is attracted to microscopic fatigue cracks by capillary forces, displacing much larger hydrocarbon oil molecules. Once in contact with the free metal surfaces within the fissure, the water breaks down and liberates atomic hydrogen. This causes further crack propagation in a process known as hydrogen embrittlement. The effects of this are apparent from the tapered rolling bearing test illustrated in Figure 3. Researchers have offered the following equation as a guide to estimating the reduced fatigue life caused by water contamination:

$$L = (100/X)\,0.6$$

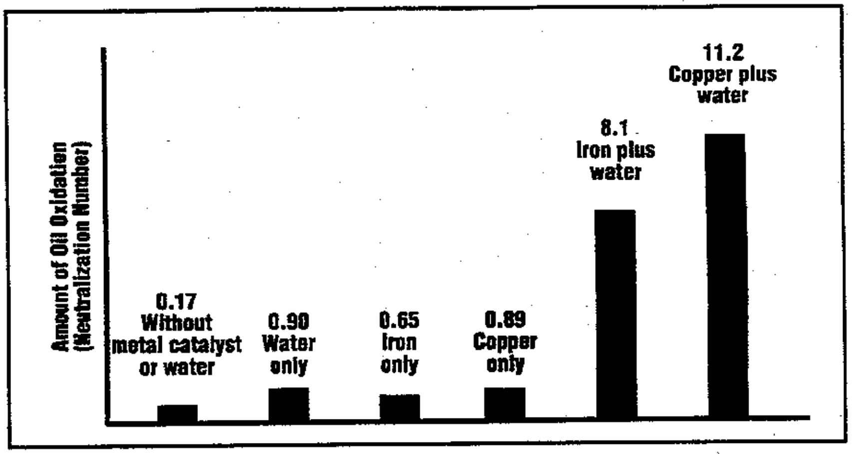
where L = the percent of rated life
X = water contamination in ppm

Water etching is a common type of corrosion occurring on bearing surfaces and raceways. This aqueous corrosion is caused primarily by the generation of hydrogen sulfide and sulfuric acid from water-induced lubricant degradation. This occurs as a result of the liberation of free sulfur during hydrolysis reactions between the lubricant and suspended water.

The elastohydrodynamic lubrication associated with rolling element bearings demands consistent oil viscosity. When water is present in the lubricant, this important property can be compromised. High local area pressures under bearing contacts can reach 100,000 to 500,000 psi depending on dynamic loading and bearing size. At such pressures the lubricant film thickness is reduced to 0.1 - 3 μm and forms a momentary solid. When moisture is present, this thin oil film can fail allowing the bearing and its raceway asperities to contact. If sustained, the result will be a marked reduction in bearing fatigue life.

For journal bearings, the hydrodynamic pressures between the shaft and bearing surfaces may not exceed 1000 psi. And, depending on such factors as speed, load, viscosity, and bearing size, film thickness can range from as low as 0.5 μm to as high as 100 μm. Moisture can reduce lubricant load-carrying ability in journal bearings causing shaft and bearing contact (wiping), especially under shock loads (Figure 4). Reduced film thicknesses (critical clearances) also increases sensitivity to smaller particle sizes where high concentrations are likely to exist (usually below the size where filters are effective).

Water also contributes to forms of corrosive and cavitation damage to journal bearing surfaces. Babbit bearings, consisting mostly of lead and tin, are easily oxidized in the presence of water and oxygen.



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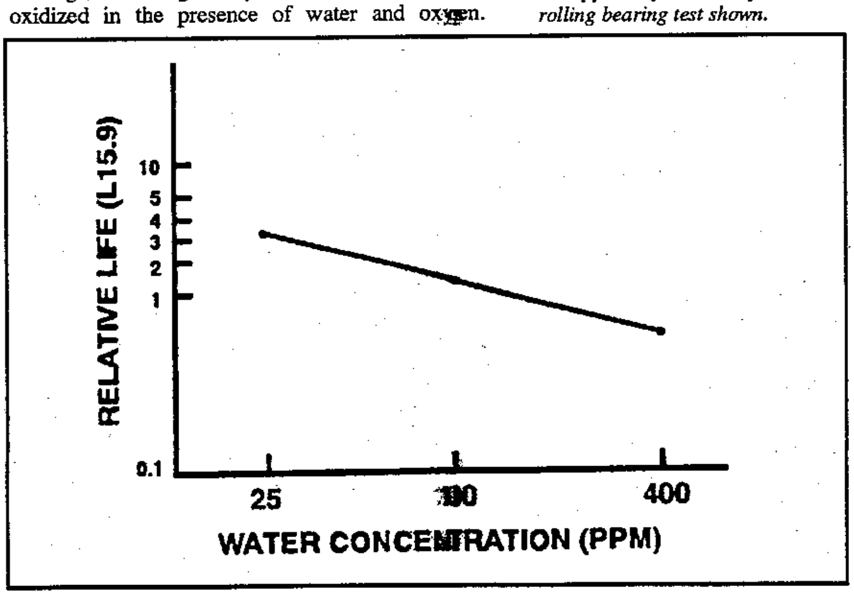


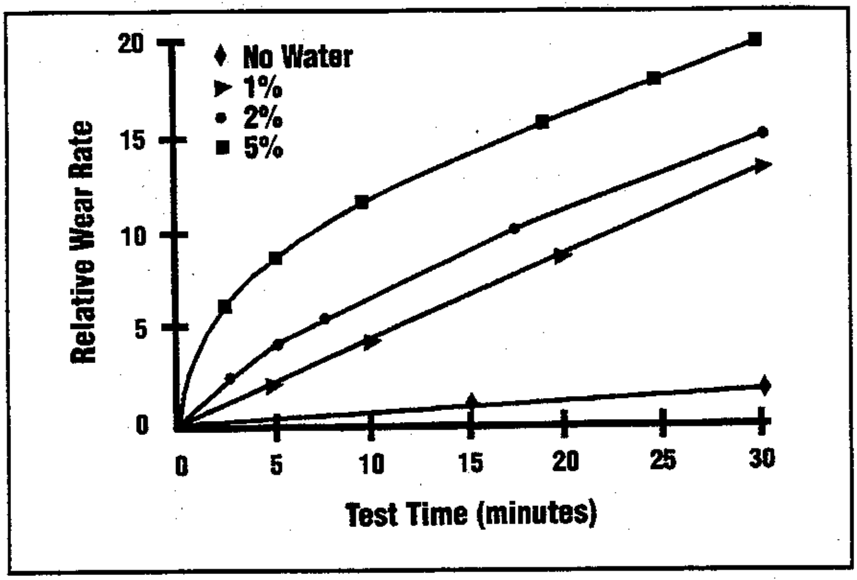


Figure 4 (Above) -
Moisture can reduce lubricant load-carrying ability in journal bearings causing shaft and bearing contact (wiping), especially under shock loads. This figure shows the influence of moisture contamination on journal bearing life.

M-LEM

Life Extension Factor (LEF)

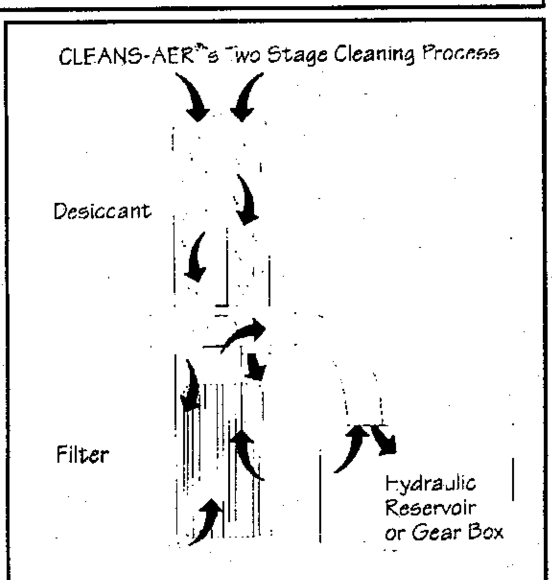
Current Moisture Level (PPM)	2	3	4	5	6	7	8	9	10
50,000	12500	6500	4500	3125	2500	2000	1500	1000	782
25,000	6250	3250	2250	1563	1250	1000	750	500	391
10,000	2500	1300	900	625	500	400	300	200	156
5,000	1250	650	450	313	250	200	150	100	78
2,500	625	325	225	156	125	100	75	50	39
1,000	250	130	90	63	50	40	30	20	16
500	125	65	45	31	25	20	15	10	8
250	63	33	23	16	13	10	8	5	4
100	25	13	9	6	5	4	3	2	2

1% water = 10,000 ppm

*Estimated life extension for mechanical systems utilizing mineral-based fluids.

Figure 5 (Above) -
The Moisture Life Extension Method (M-LEM) was developed to assist in quantifying the benefit of lower moisture targets. It must be emphasized that benefits are available only when lower stabilized moisture levels are achieved. From the M-LEM, the estimated extension in bearing life (MTBF) can be determined.

Figure 6 (Right) -
Flapper-valve style desiccant breathers are especially effective for vented systems where humid air intake and condensation or absorption is a possibility. If moisture is suspended in the lubricant, water removing filters and/or separators must be used.



Vaporous cavitation associated with the implosion of water vapor can form honeycomb-like pitting on bearing surfaces. A variety of chemical and electrochemical forms of surface failure have been reported as a result of moisture in journal bearing lubricants.

Water Sequestration and Control

The presence of environmental water makes it difficult to totally prevent it from combining with oil. However, its presence can be greatly minimized and its effect on lubricant life and machine surface damage considerably reduced. The Target-Exclusion-Detection proactive maintenance strategy, is one approach for achieving contamination control of moisture.

Target - The first step in any proactive maintenance effort is to set targets or limits, beyond which a particular condition, such as a contaminant level, must not exceed. This target may be a level of moisture in the lubricant that will often vary from application to application. Such applications as steam turbines, diesel engines, dryer rollers (paper mills), screw compressors, and industrial gear boxes have different problems with moisture control. As a general rule, 100 ppm is a useful limit for many applications to provide adequate lubricant and bearing life, though higher limits may sometimes be more practical.

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Exclusion - A contaminant that is excluded is one that never enters the machine sump and does not come in contact with the lubricant. Moisture can effectively be excluded with the use of seals and breathers in bearing applications. Flapper-valve style desiccant breathers are especially effective for vented systems where humid air intake and condensation or absorption is a possibility (Figure 6). If moisture is suspended in the lubricant, water removing filters and/or separators must be used.

Detection - Proactive maintenance demands a constant feedback loop. A moisture contamination control program should include routine, on-site monitoring of lubricant moisture levels to insure these levels are within target limits. A new technology has been introduced for user-level moisture detection in the form of a probe and a hand-held data collector (Figure 7). At the tip of the probe, which is submerged in an oil sample, is a miniature heating element. During a test, this heating element glows at constant temperature causing suspended moisture to vigorously vaporize emitting a distinctive acoustic signal known as crackling.

A microphone mounted adjacent to the heating element picks up this signal and electronically passes it to the data collector for analysis. The algorithm in the data collector is calibrated to convert signal threshold crossings per unit time into moisture levels in ppm or percentage. The unit is able to detect suspended moisture to as low as 25 ppm and as high as 10,000 ppm. A typical test takes less than 30 seconds.

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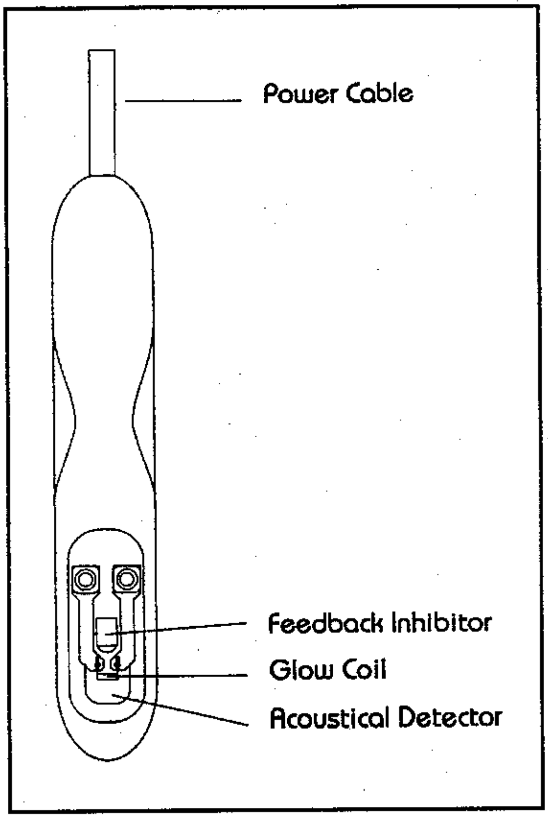

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References

Beercheck, Richard C., "How Dirt and Water Slash Bearing Life", Machine Design, July, 1978.

Bloch, Heinz P., Exxon Chemical Company, USA, "Criteria for Water Removal from Mechanical Drive Steam Turbine Lube Oils." Lubrication Engineering, Volume 36, 12, 699-707.

Cantley, Richard E., The Timken Company, "The Effect of Water in Lubricating Oil on Bearing Fatigue Life", ASLE Transactions, Volume 20, 3, 244-248.

Booser, E. Richard, Editor, CRC Handbook of Lubrication (Theory and Practice of Tribology) Volume II - Theory and Design, 1984.

Fitch, E. C., Proactive Maintenance for Mechanical Systems, FES, Inc., 1992.

Fitch, E. C., Fluid Contamination Control, FES, Inc., 1988.

Fitch, J. C., "Contaminant Monitoring Targets Root Causes of Machinery Problems," P/PM TECHNOLOGY, March/April, 1991.

Fitch, J. C., Oil Analysis and Proactive Maintenance - A Complete Users Guide For Maintenance Professionals, Diagnetics, Inc., 1994, 1994-5 Edition.

Fitch, J. C., "Water Removing Filters, The Latest Entry Into Hydraulic Filtration," Hydraulics & Pneumatics, January, 1989.

Wooding, P. S., W. R. Murphy, S. J. Leonardi, E. L. Armstrong "Evaluation of Water-Accelerated Bearing Fatigue in Oil-Lubricated Ball Bearings," Lubrication Engineering, January, 1978.

Zaretsky, Erwin V., Editor, STLE Life Factors for Rolling Bearings, Society of Tribologists and Lubrication Engineers, 1992.