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MOISTURE – THE SECOND MOST DESTRUCTIVE LUBRICANT CONTAMINANT

PART ONE - ITS EFFECTS ON BEARING LIFE

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Introduction

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

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

States of Co-existence in the Lubricant

Once water enters the casing of a machine where bearings are used, such as an engine, turbine, or gear box, it may move through several chemical and physical states. These changes are complex, but important to understanding how to control and analyze its movements. To begin with, water will enter an oil in generally one of the five following ways:

(1) **Absorption.** Oil is hygroscopic to a certain extent, 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 solubility in the oil. Depending on temperature and pressure, this solubility limit will vary from about 100 ppm for low additive oil to several thousand ppm for high additive and certain synthetic oils. For any given water-in-oil saturation point and relative humidity of ambient air, an equilibrium will eventually be attained where the moisture moving from the air to the oil, and also from the oil to the air, is equal (see Figure 1). Absorbed water is always dissolved in the oil at first, but may later, due to temperature/pressure changes, be condensed out to a free or emulsified state.

(2) **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 and run down the casing walls to the bottom forming a layer of free water or puddle.

(3) **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.

(4) **Combustion/Oxidation/Neutralization.** Fuel combustion in engines forms water in the exhaust gases as a by-product. This is combined with the water from the induction air. Problems associated with worn rings/liners and improper scavenging can cause water to enter the lube oil. Low jacket-water temperature and intermittent operation may prevent the water from easily vaporizing out of the oil compartment. Water can also be created in oil as the chemical reaction product resulting from certain types of corrosion and oxidation processes. In engine oils, water is also formed when alkalinity improvers neutralize acids formed during combustion.

(5) **Free Water Entry.** During oil changes or the addition of makeup fluid, water can be introduced to oil compartment. Condensation of water 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 the oil, the water molecule is polar, which greatly limits its ability to dissolve. Many additives have polar extremities which can markedly increase water's limit of solubility. In the absence of dissolved polar compounds to which water can attach, water may cling to hydrophilic metal surfaces or even form a thin film around polar solid contaminants such as silica particles. Or, 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 further facilitated where air and oil mix (such conditions where high air/oil surface area are created) such as in splash lubricated and oil mist systems or any fluid system where a stable foam may exist.

If increasing amounts of water molecules are unable to find polar compounds to attach themselves, the oil is said to be saturated. Any additional amounts of water will result in a supersaturated condition causing free water to be suspended or settle in puddles 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. This causes 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 microemulsion of water in oil that inhibits coalescence and settling of the water.

The Effects of Water on Additives and Base Stock Lubricants

With few exceptions, the chemical and physical stability of lubricants are threatened by even the slightest amount of suspended water. Water can promote a host of chemical reactions (hydrolysis) with compounds and atomic species including oil additives, base stock and suspended contaminants. In combination with oxygen, heat, and metal catalysts, water is known to promote the oxidation and the formation of free radicals and peroxide compounds. Oxidation inhibitors are sacrificed by both neutralizing peroxides and breaking oxidation chain reactions to form stable compounds. Other oxidation inhibitors are known to 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, to be destroyed by as little as one drop of water in a gallon of oil, with oil temperature above 180°F.

Water is also known to attack rust inhibitors, viscosity improvers, and the oil's base stock. The effects are undesirable by-products such as varnish, sludge, organic and inorganic acids, surface deposits and lubricant thickening (polymerization). Large amounts of emulsified water can lower viscosity, thereby reducing a lubricant's load carrying ability. When water is combined with metal catalysts such as iron or copper, accelerated stressing of the oil can occur. This results in base stock oxidation and the forming of free radicals (which continue the oxidation process), hydroperoxides, and acids (see figure 2).

The Effects of Water on Bearing Surfaces and Bearing Life

The deleterious effects of water on the fatigue life of rolling element bearings is widely documented. According to SKF, "It is well-known that free water in lubricating oil decreases the life of rolling element bearings by ten to more than a hundred times. . ." Already mentioned are the many damaging effects water causes to the lubricant itself, resulting in a corrosive environment and diminished boundary layer and hydrodynamic protection.

The exact mechanisms by which water promotes bearing failure are not fully understood. There is much evidence that water is attracted to microscopic fatigue cracks by capillary forces in preference to the 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, in turn, causes further crack propagation, 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 their 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 invades 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 (see Figure 4). Reduced film thicknesses (critical clearances) also increases particle contaminant sensitivity to smaller particle sizes where high concentrations are likely to exist, usually below the size where filters are effective.

Water also contributes to various 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. 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 to be caused by moisture in journal bearing lubricants.

Water Sequestration and Control

The universal environmental presence of water makes any effort to totally prevent it from combining with the oil of limited potential success. However, its entry can be greatly minimized and its effect on lubricant life and machine surface damage can be considerably reduced. Using the Target-Exclusion-Detection (TED) three-step, proactive maintenance strategy, is a recommended approach for achieving contamination control of moisture.

1. 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. With moisture, the target is a level of moisture in the lubricant that must not be exceeded. To a great extent, this target will vary from application to application. Such applications as steam turbines, diesel engines, dryer rollers (paper mills), screw compressors, and industrial gear boxes all have distinctly different challenges when it comes to moisture control. As a general rule, 100 ppm is a reliable limit for many applications in terms of lubricant and bearing life. However, in view of the ingression potential of moisture in certain applications, higher limits may be more practical.

The Moisture Life Extension Method (M-LEM) was developed to assist bearing users with quantifying the benefit of lower moisture targets (see Figure 5). 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.

2. **EXCLUSION.** A contaminant that is excluded is one that never enters the machine housing and makes no contact with the lubricant. Moisture can be excluded by effective 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/absorption is a possibility (see Figure 6). If moisture is allowed to be suspended in the lubricant, water removing filters and/or separators must be employed.

3. **DETECTION.** Proactive maintenance demands a constant feedback loop. By definition, all "controlled" systems must have regular feedback. 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 (see 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.

SUMMARY

Moisture is known to enter lubricated bearing systems in several different ways resulting in dissolved, suspended or free water. Both dissolved and suspended water can promote rapid oxidation of the lubricant's additives and base stock resulting in diminished lubricant performance. Rolling element bearings may experience reduced fatigue life due to hydrogen embrittlement caused by water penetrated bearing surfaces. Many other moisture-induced wear and corrosion processes are common in both rolling element and journal bearings. The best defense against moisture contamination is a three-step, proactive maintenance strategy called Target-Exclusion-Detection (TED). Only when lower moisture levels are consistently stabilized can the life extension of lubricants and bearings be effectively achieved.

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Figure 1: Hygroscopic Characteristics of Fluids

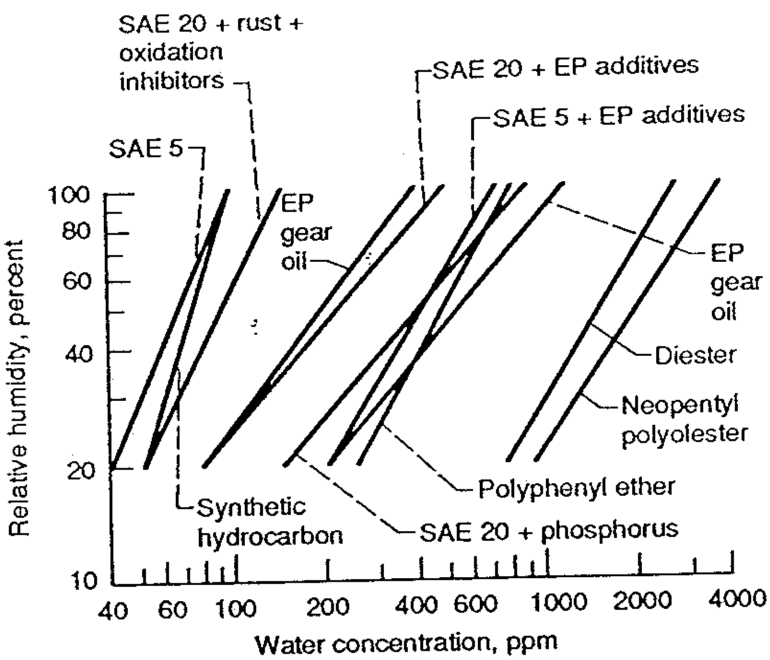


Figure 2: Influence of Moisture and Metal Catalysts on Oil Oxidation

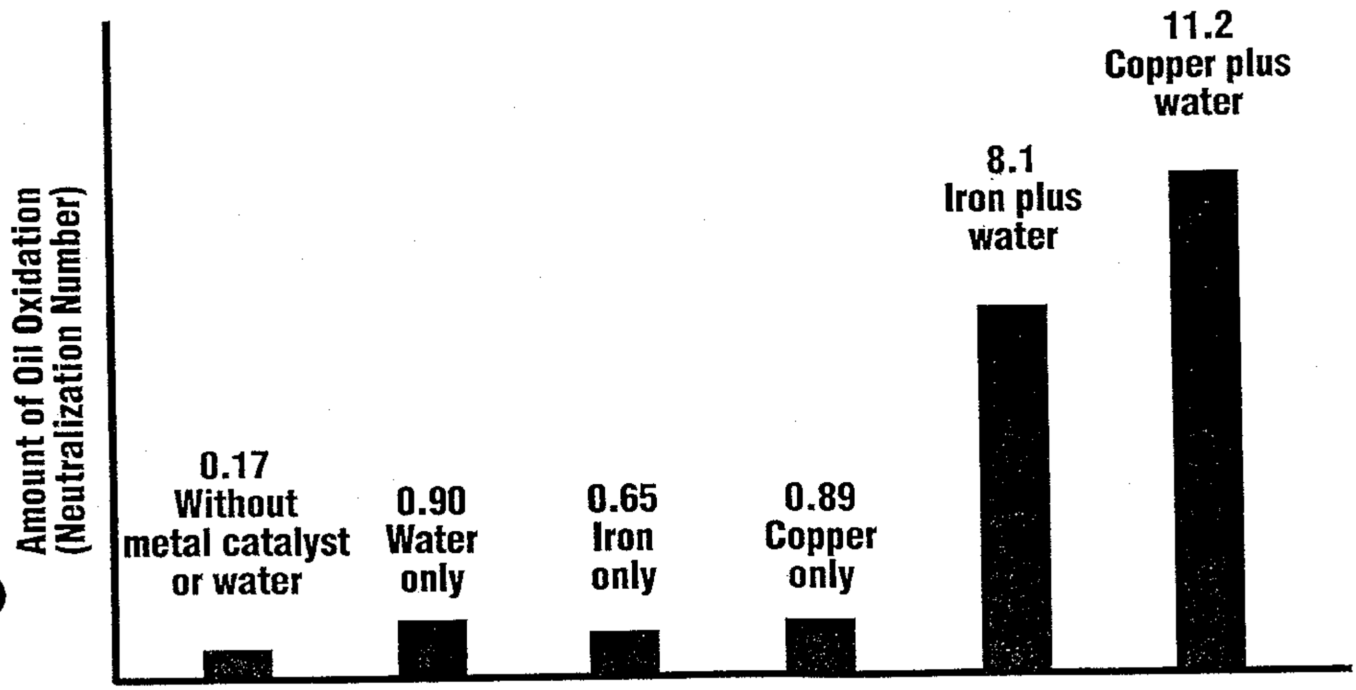
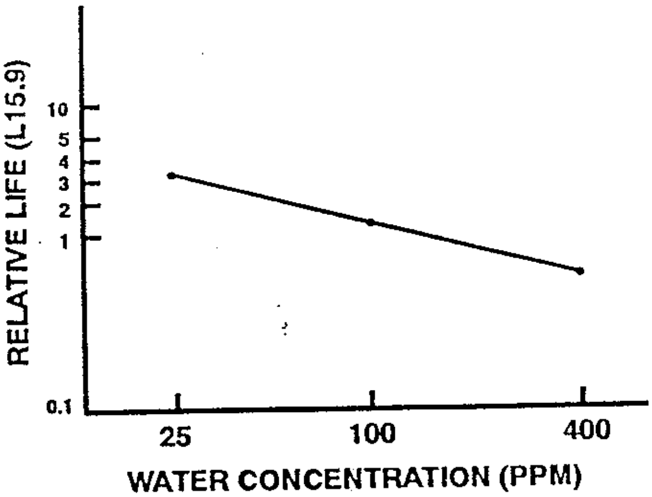


Figure 3: Influence of Moisture Contamination on Tapered Bearing Fatigue Life



2700 rpm
150° F
Elasto-hydrodynamic
Film Thickness 0.29μm

Figure 4: Influence of Moisture Contamination on Journal Bearing Life

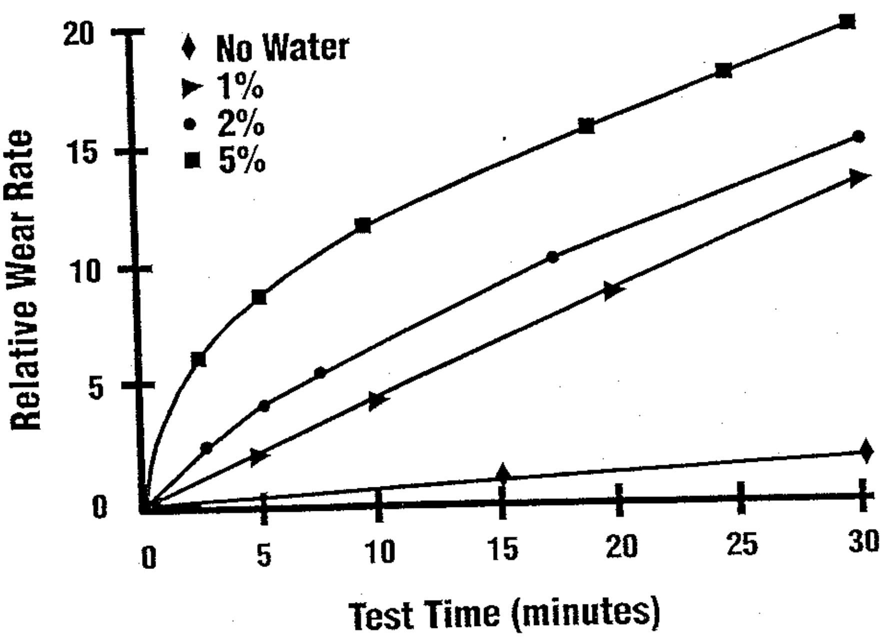


Figure 5: Moisture Life Extension Method to Calculate Bearing Life Improvement

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.**

Example: By reducing average fluid moisture levels from 2500 ppm to 156 ppm machine life (MTBF) is extended by a factor of 5.

Figure 6: Desiccant Flapper-Valve Style Breather

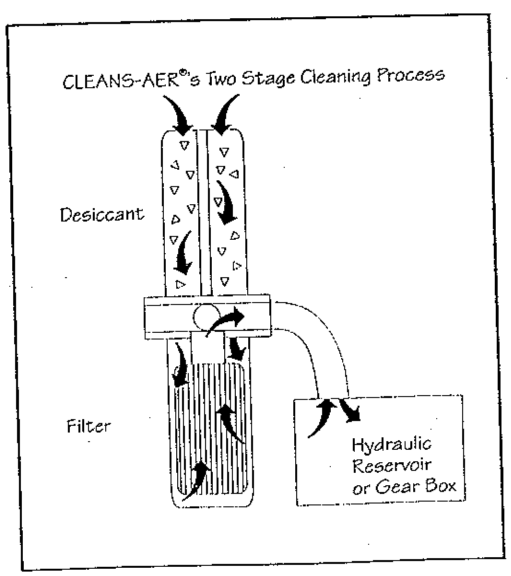


Figure 7: Schematic of Moisture Detection Sensor