Water Contamination: Management of Water During the Lubricant Life Cycle

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Introduction: We've all heard the saying, "Oil and water don't mix." Often, this is true, but not always. While certain lubricant formulations are designed to separate from water, others are intended to form a stable emulsion with water. In either case, water becomes a contaminant and can cause major problems both to the lubricants and to the equipment the lubricants are supposed to keep running smoothly and reliably. It is therefore critical to understand the operating needs for specific lubricant applications and to know their desirable water management properties in order to remove water contamination as thoroughly and efficiently as possible. This paper addresses these issues, describes the common causes, characteristics, and results of water contamination, and outlines a variety of techniques for separating and removing water from machine lubricants.

Selecting the Proper Lubricant: Applications for lubricants in industrial and consumer products are almost endless. As a result, there is no *cookie cutter* approach that works for every application, and selection of the appropriate lubricant is critical to equipment performance. Certain lubricants must be formulated to separate easily from water so that the water can be removed, while others must hold on to the water. For example, in a power generation turbine, water can get into the oil either through condensation from the air or via a leak in a coolant system. Because water is detrimental to the moving parts in the turbine and causes rapid degradation of the oil, turbines are often equipped with water removal equipment. However, in a typical internal combustion engine, the lubricant is required to manage high levels of contamination, such as deposits, soot, and combustion by-products. One of the by-products of fuel combustion is water. People do not want to climb under their cars every day to drain settled water from the bottom of the crankcase. Consequently, engine oils are designed to disperse and hold onto water until the oil gets hot enough to "cook" the water out during vehicle operation.

How Oil and Water Are Mixed: A fully-formulated lubricant is composed of a base oil and additives. The engine oil example mentioned above suggests that it is possible to make oil and water mix. In most cases, it is the presence of *polar* additives in fresh, clean lubricant that results in a shift in oil polarity and allows it to have some affinity with, or attraction to, water. Water molecules also have *polar* properties – meaning that they have an uneven distribution of electron density. Water has partial positive charges near its two hydrogen atoms and a partial negative charge near its single oxygen atom because of unshared pairs of electrons. An electrostatic attraction between the partial positive charge near the hydrogen atoms and the partial negative charge near the oxygen creates the water molecule's hydrogen bond. In addition, these partial positive and negative charges create the polarity that leads to mutual attraction between water and the polar additives. As it turns out, some of the degradation mechanisms that occur during lubricant use can also produce a polarity shift in oil. Unlike the engine oil example, this change leads to negative consequences in machinery where the oil temperature never gets hot enough to "cook out" the water. In these situations, the water must be *physically removed*. Once a polarity shift has occurred in used lubricant, however, physical water removal becomes much more difficult.

Lubricant Polarity Shift Mechanism: The following is a four-step mechanism that results in changes to oil, causing its polarity to change:

Step 1: Infiltration
Step 2: Catalysis (Galvanic Reactions)
Step 3: Oxidation & Hydrolysis
Step 4: Emulsification

Infiltration: There are various ways for water to gain access into lubricant systems, such as through improper vents, defective seals, housing openings, steam system leaks, or from leaky internal heat exchangers or oil coolers. Loose or missing storage tank caps or hatches and transfer equipment, such as hoses and pumps left unprotected when not in use, can permit incidental or weather-related water infiltration. As already noted, water is also a normal combustion by-product, and blow-by exhaust gases from combustion processes can enter lubricant systems. (1)

Catalysis: Water is *polar* – as are metal surfaces. This polarity results in mutual attraction between water and the metal surfaces inside machinery. Certain lubricant additives, such as detergents, dispersants, and some antiwear additives, are also polar. Polar additives are naturally attracted to the water and metal surfaces. The metal surfaces serve as a catalyst, speeding up reactions between the water, the additives, and the metal surfaces themselves. One possible result is a stable, almost soap-like, emulsion that collects within the lubricant and on metal surfaces. Another possible result is a galvanic electrolytic reaction between the metal and oxygen in the water. This produces rust and/or carbonaceous material on the metal surfaces. Either way, the catalysis step traps water inside the machine in forms that are not easily removable. The water forms immobile substances that are not easily carried to filters or dehydration equipment, and it remains present to accelerate the degradation of the oil.

Oxidation & Hydrolysis: The mechanism for lubricant oxidation has been well documented. As the name indicates, oxidation is the reaction of lubricant base stock with oxygen. The final outcomes of oxidation reactions are the formation of oxygen-containing products called free-radical acids, esters, alcohols, ketones, polar compounds, and polymeric materials.(2) Oxidized oil has a heightened affinity with water. The solubility of water increases in oxidized oil, and it does not separate easily.

Hydrolysis is a reaction between the oxygenated esters and ketones with the hydroxyl group in water. Water naturally breaks down into a weak acid and a hydroxyl group through a process called dissociation. Hydrolysis is yet another reaction that occurs between water and used lubricant to increase the affinity between water and the lubricant and to make water removal more difficult.

Emulsification: The previous three stages described the infiltration routes of water into the lubricant, how water accelerates the degradation of the lubricant, and how degradation results in a change to the polarity of the oil. Once the polarity of the lubricant has changed, the final stage of the polarity shift mechanism has been reached. It is called *emulsification*. An emulsion is a stable mixture of two insoluble liquids, like oil and water. Once this point is reached with certain oils, it is impossible to “break” the emulsion and remove the water from the oil. Emulsified oil can cause all of the problems noted in Table 1.

Types of Water Contamination: Water contamination exists in three forms within lubricated machinery: *free water*, *dissolved water*, and *emulsion*. **Free water**, as the name suggests, is water that separates from the oil and collects in pools in low areas within a machine or in its oil reservoir. Free water is the easiest form of water to remove from a lubricant because it is present as a separate layer below the lubricant. The separated water layer can be drained away. **Dissolved water** is solublized into the oil and cannot be easily separated. As noted earlier, water and oil generally do not mix, so the concentration of dissolved water in new oil is usually rather low. **Emulsion** is a stable, milky mixture of oil and water that is difficult to separate. It differs from dissolved water in that it is almost a gel-like dispersion of water droplets within the oil. If it is not properly managed, water in any of these forms can result in problems for mechanical equipment and lubricants used within the equipment. Table 1 provides a list of problems caused by water contamination and a brief description of each.

Sample on left shows water that has not separated from the oil.
Sample on right shows water that is in process of separating from the oil.

Table 1

Problems Caused by Water Contamination	
Problem	**Description**
Hydrogen-Induced Fractures	This is sometimes called embrittlement or blistering. Water is attracted to microscopic fatigue cracks by capillary action. Water breaks down and liberates atomic hydrogen and causes further crack propagation and fracture. Risk posed by both soluble and free water.
Corrosion	Corrosion is commonly called rusting. Free water and soluble water both result in increased corrosive potential of acids. Results are etched and pitted surfaces and in worst cases formation of abrasive iron oxides that can break off and accelerate wear.
Oxidation	Oxidation is the degradation of the lubricant due to elevated temperatures in the presence of oxygen. When water and metal particles are present, antioxidants in the lubricant are consumed even faster. Results in corrosion, sludge, varnish, and impaired oil flow.
Additive Depletion	Water depletes or diminishes the performance of lubricant additives, including antioxidants, AW, EP, rust inhibitors, dispersants, detergents, and demulsifying agents. It hydrolyzes, agglomerates, washes out, or transforms additives, and sometimes results in the formation of acids or sludge puddles on sump floors.
Oil Flow Restrictions	Water is highly polar and has the ability to attach to oil impurities that are also polar (for example, oxides, spent additives, particles, carbon fines, and resin) to form sludge balls and emulsions. When sludge balls accumulate in orifices, feed lines, or filters, they can impede flow and cause lubricant starvations and ultimate failure.
Aeration & Foam	Water lowers oil's interfacial tension, which can cripple its air-handling ability, leading to aeration and foam. Air weakens oil films, increases heat, induces oxidation, causes cavitation, and interferes with oil flow.
Impaired Film Strength	Bearings depend upon oil viscosity to provide critical clearance under a load. Water globules pulled into a bearing load zone reduce surface clearance and result in bumping or rubbing of opposing surfaces. This should never occur in hydrodynamic applications such as turbine main bearings. Water can flash or explode into superheated steam in bearing load zones, and this can sharply disrupt oil films and potentially fracture surfaces.
Microbial Contamination	Water is known to promote the growth of microorganisms, such as fungi and bacteria, which can form thick biomass suspensions over time that can plug filters and interfere with oil flow. Microbes also produce waste by-products that are corrosive.
Water Washing	Pressurized water sprays can directly wash an additive out of a lubricant zone. Lubricant density is lower than that of water, and too much free water can displace lubricant if allowed to accumulate in a bearing. As noted earlier, this can cause impaired film strength.

(Adapted from Sources 3 & 4)

Water Removal Techniques:

Various well-established methods for removing water exist, including the following:

- Desiccation
- Gravity Separation
- Centrifugal Separation
- Coalescing Separation
- Absorbent Polymer Separation
- Vacuum Separation

Desiccation: The best way to eliminate water from any lubricant application is to stop it from getting into the lubricant supply or into the machinery in the first place. In some cases, this is very challenging, but a common technique for eliminating water infiltration into a lubricant is with desiccant air breathers. A desiccant air breather contains material that absorbs water from ambient air before it enters the machine. Breathers can be attached to fill spouts or open breather ports. Most lubricant reservoirs “breathe out” as well as “breathing in,” so desiccant breathers can also serve to remove water that may have been introduced to oils during production, handling, and/or filling.

Gravity Separation: The most basic method of water removal is gravity separation. As the name suggests, gravity can separate fluids because of its stronger pull on the more dense fluid, which separates it from the less dense, or lighter, fluid. In relation to turbine oils, water is the denser fluid. To employ gravity separation, either the system is temporarily shutdown or the lubricant is transferred to a residence, or reservoir. The goal is to slow down the flow of the oil and, in so doing, minimize the agitation that physically mixes the oil and water together. The water will then settle into a liquid layer on the bottom of the reservoir, where it can be drained off. The downside to this water removal technique is that it requires time for separation and drainage, during which the oil cannot be circulating through the system. If this method fails to separate the oil and water, significant time may have been wasted.

Centrifugal Separation: Gravity alone is often not enough to separate water from oils in a reasonable amount of time. In this case, purifying systems called centrifugal separators are used to “push” the water from turbine and other oils by means of centrifugal force. This technique bears similarities to the spin cycle on consumer laundry washers. It takes advantage of the differences in density between water and oil: The water is spun free of the less dense oil and then drained from the bottom of the separator by gravity. Compared to gravity separation, centrifugal separation requires much less residence time, allows the oil to remain in motion during the separation process, and achieves separation faster. Also, this technique can sometimes remove water from oil that has developed some affinity with the water. But it does require energy to operate.

Coalescing Separation: Sometimes the surface tension between oil and water increases to a point where neither gravity nor centrifugal force is sufficient to remove the water from the oil. In this situation, a coalescence separation system might be employed. Coalescence involves forcing the water and oil through a screen-like feature of the system. The oil is able to pass through the screen; the water cannot pass through, collects, flows down by gravity, and is then drained from the system. As in a centrifugal system, the oil remains in motion. Also on the positive side, the turbine does not have to be shut down or be fitted with a settling reservoir. A coalescence system may not require that the oil be out of service. Like centrifugal separators, coalescence separators use energy inputs to remove the water.

Absorbent Polymer Separation: Absorbent polymeric materials filter water from turbine oil – just as filters are used to remove particulate contamination from such oils. Absorbent polymer technology is used in disposable baby diapers to remove moisture from a baby's bottom. In similar fashion, oil is passed through a polymeric filtration system. The material in these filters effectively removes the water while allowing the oil to travel back into service. This type of system can be very effective, but it is not practical for high water contamination. The polymeric media can contain only so much water before they must be replaced. Then the media must either be disposed of or recharged (dehydrated), adding to the costs of an already expensive system.

Vacuum Separation: The last water removal method that we will discuss here is vacuum separation. This technique takes advantage of the fact that the vapor pressure of water is lower than that of most turbine oils. In this technique, the contaminated oil/water mixture is passed through a vacuum chamber where the water is literally drawn out of the oil as water vapor. This approach can work well with most turbine oils, except those that contain volatile ingredients. In vacuum separation, the volatile ingredients would be removed right along with the water. This type of system can be effective, but it is very expensive to operate.

Finally, it must be noted that lubricant formulation plays a key role in mitigating the problem of water contamination. Base oil and additive composition can have significant impacts on the ease of water removal and on the effectiveness of the techniques we have discussed. Dennis Morgan of AMS Filtration, whose company provides water removal solutions to the turbine industry, notes:

> *"I'm not sure what has changed within the last several years, but the removal of water from some turbine systems has become a real challenge. Field experiences are beginning to point to various lubricants that are more difficult to remove water from than others. In questioning the users, we have learned that their lubricant suppliers have recently changed their turbine oil chemistry. It seems to be base oil related."* (5)

Conclusion: Reliable machine operation is of vital importance in an industrial society – to producers and consumers alike. Water contamination of machine lubricants can cause a wide range of operational problems and significantly affect machine reliability and longevity. Therefore, machine reliability often starts with picking a lubricant that can neutralize or mitigate the effects of water contamination. There are many lubricant choices available for users to consider, and it is always important that they evaluate the original equipment manufacturer's specifications prior to selecting the lubricant.

Every effort should be made to keep water from entering lubricated mechanical systems: If water from the operating environment finds its way into lubricant systems, it can cause a polarity shift in many lubricant formulations. This shift results in dramatic loss of the lubricant's protective and water management properties. Selecting a robust lubricant upfront will help combat polarity shift changes. But when water enters the operating environment, it must be removed, and there are six well-established techniques for removing water and controlling water contamination. Today's more advanced lubricant suppliers not only specialize in lubricants but also have the expertise to assist customers with their total water removal plans and appropriate techniques. Managing water contamination should always be a primary focus of any machine lubrication program.

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5.08.09