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MIXING Oil & Water: A Recipe for Downtime!

While conventional wisdom would hold that oil and water don't mix, in reality, they do! Even clean, dry oil can hold minute amounts of water in the dissolved phase. Dissolved water can be thought about in the same terms as water vapor in the atmosphere.

While we know there's always some water in the air, provided the concentration is low enough and the temperature high enough, we don't see visible evidence of the water in the form of condensation (dew), fog, or rain. But as soon as the levels of water in the atmosphere increase or the temperature decreases, water starts to visibly come out of solution. This is why on a cool spring morning we often start the day with fog or mist, particularly in coastal regions, where water levels tend to be higher.

Oil is no different. Small amounts of moisture are readily attracted to oil, a term we sometimes refer to as *hygroscopic*. Hygroscopic simply means that the material—in this case, oil—has an affinity for moisture. The degree to which an oil will absorb moisture will depend on a number of factors including base oil type and age, additive composition and the level of contamination.

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Typically speaking, the more polar the base oil, the more water can be held in suspension. For this reason, high polar base oils such as phosphate esters or polyalkylene glycols are significantly more hygroscopic and hence hold more water in the dissolved phase than petroleum oils. Likewise, highly refined mineral oils and synthetics will hold less water in the dissolved phase than less highly refined Group I or II mineral oils due to the absence of cyclo- aromatics, naphthenes, and other impurities that tend to absorb moisture more readily. Aged fluids also tend to hold more water in solution due to the by-product of base oil degradation, which tends to be more polar than the base oil molecules themselves.

Aside from base oils, additive composition also has a dramatic effect on an oil's affinity for water. In lightly additized oils such as turbine and other R&O type oils, there are very few additives and thus there is minimal change in the ability of the oil to absorb moisture. Other fluids, however, such as hydraulic fluids and gear oils, contain polar additives which tend to increase the amount of moisture an oil will hold in the dissolved phase. Very heavily additized oils such as engine oils or tractor fluids have an even greater affinity for moisture since they typically contain additives anywhere from 15–30% by volume, many of which are polar.

Engine oils in particular are prone to water absorption since most engine oils contain detergent additives. Detergent additives are designed to have both polar and nonpolar ends which causes them to serve as a "bridge," binding water (polar) and oil (nonpolar) together into what is commonly called an emulsion. An emulsion is the cloudy oil-water mixture we've all seen that sometimes looks like chocolate milk. Emulsions can be described as either stable or unstable. A stable emulsion refers to an oil-water mixture that is tightly bound with little-to-no tendency to separate, while an unstable emulsion will tend to separate back into oil and water phases, particularly at elevated temperatures. Generally speaking, lightly additized oils do not form emulsions, and if they do, they tend to be unstable. Heavily additized oils on the other hand are far more prone to forming a stable emulsion. In fact, as little as 500 ppm (0.05%) of diesel engine oil contamination in a turbine oil can completely destroy the turbine oils ability to shed water—a property usually referred to as *demulsibility*.

With the exception of oils used for insulating electric equipment, dissolved moisture in an oil is of little concern to the lubricating quality or performance of the lubricant. But when water comes out of a solution, and forms either an emulsion or free water on the bottom of the sump, the reliability of equipment can be seriously compromised. In rolling contacts such as those found in rolling element bearings, the presence of water in the emulsified phase can result in as much as a 75% reduction on bearing life (Figure 2), while in hydrodynamic contacts such as journal bearings, reducing water content from 1000 ppm to 250 ppm can increase bearing life by as much as 50%.

Water in oil affects machines in a variety of ways. The first is purely mechanical. Put simply, water doesn't lubricate as well as oil! In situations where the lubricant is subjected to a sudden change in pressure, flash vaporization followed by rapid condensation of the water can occur. Under such circumstances, the rapidly condensing vapor can form a microjet of steam which implodes at the machine surface. A common example of this occurring is in a hydraulic pump where the hydraulic fluid and any entrained water rapidly cycles from low pressure on the suction side of the pump, to very high pressure on the discharge side. When this occurs, mechanical damage to the pump can occur—an effect referred to as *vaporous cavitation*. A similar effect can be seen when oil under fairly low pressure enters a hydrodynamic contact such as a journal bearing. Again, a sudden change in pressure can result in flash vaporization of the water and subsequent damage to the bearing surfaces.

But water has other deleterious effects on a lubrication system. For example, as a lubricant degrades, oil soluble by-products are formed. While these are usually in solution in the oil, in the presence of free or emulsified water, these by-products can be drawn out of the oil causing a sticky, resinous material to form in the system. While not always the case, oftentimes, sludge and varnish formulation together with the resultant problems such as valve stiction or restricted oil flow can be directly attributed to the presence of moisture in the oil.

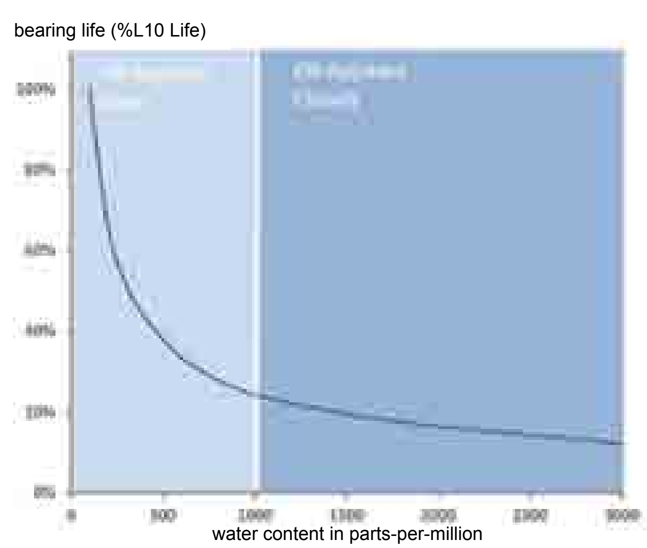

Figure 2: Life Expectancy of Rolling Element Bearings Versus Water Content

In some types of fluid such as ester-based synthetics, water can chemically react with the base oil under certain conditions, a process known as *hydrolysis*. Left unchecked, hydrolysis can result in the formation of sludge, acids and deposit throughout the system. Electrohydraulic control (EHC) systems in steam turbines which historically have used phosphate ester fire-resistant fluids are particularly susceptible to hydrolysis.

Even in petroleum-based fluids, water has an effect on the base oil. While water itself will not react with hydrocarbons, it does help to promote and catalyze base oil oxidation, particularly in the presence of certain catalytic wear metals such as copper, iron, and tin. In fact, as little as 0.1% water in oil can increase an oil's oxidation rate up to ten times under certain conditions.

Finally there are the direct chemical effects on the machine's surfaces, most notably rust. Rust causes loss of surface profile, embrittlement of the surface, and deposit formation as rust particles flake off of surfaces and fall into the lube oil system. Not only does this destroy the surface finish, but the rust particles then circulate throughout the system causing particle-induced failures such as 3-body abrasion or fatigue.

While all machines are at risk, of particular concern are those that operate in high humidity environments and/or have cycling temperatures. The reason for this is quite simple: the solubility of water in oil is temperature dependent—the hotter the temperature, the more water can be dissolved in the oil. Of course this only goes so far. Once you approach the boiling point of water (212^{0}F at atmospheric pressure), water will start to evaporate from the oil. But since most of our machines don't operate this hot, water will readily dissolve in the oil if it is present either from the process or ambient environment.

Humid environments are particularly troublesome because air and oil in contact try to maintain the same relative humidity. This is based on Henry's law which states: *"At a constant temperature, the amount of a given gas (water vapor) dissolved in a given type and volume of liquid (oil) is directly proportional to the partial pressure of that gas in equilibrium with that liquid."* Put simply, if the headspace above a lubricant is saturated, the oil will also be saturated, meaning much of the water present in the oil will be either free or emulsified.

This can be of particular concern for stop-start equipment where production shifts or intermittent usage mean that oil temperatures cycle from operating (high) to ambient (low) frequently. While the oil may be below saturation during operation, as the temperature cools down, water comes out of solution and becomes free or emulsified. As an example, a circulating lube oil at 140^{0}F may have 500 ppm of water (0.05%) present in the dissolved phase, but cooling that oil down to 80^{0}F may result in as much as 400 ppm coming out of solution!

So don't just take water for granted just because your process uses water, or your equipment operates in high ambient moisture conditions; look for ways to eliminate moisture to help extend equipment life. Stay tuned for Part 2 of this article, when we'll discuss techniques for eliminating moisture.

Mark Barnes recently joined Des-Case Corporation, a leader in the field of contamination control and lubrication management as Vice President of the newly formed Equipment Reliability Services team. Mark has been an active consultant and educator in the maintenance and reliability field for over 17 years. Mark holds a PhD in Analytical Chemistry and is a Certified Maintenance and Reliability Professional (CMRP) through SMRP. Visit www.descase.com