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Air: The Forgotten Contaminant

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Entrained air, visible in this sight glass, can affect the bulk modulus of hydraulic fluids, which in turn affects their compressibility.

Air exists in oil exists in one of four states and can have a significant impact on lubricants and machines.

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With good reason, much has been made of the impact that contaminants such as particles and moisture have on lubrication and asset reliability. In most machines, particle and moisture contamination accounts for as much as 60% to 80% of lubrication-related problems. In hydraulic systems the numbers are even higher, often approaching 80% to 90%. For this reason, a robust contamination-control strategy is the first line of defense when developing an asset lubrication policy.

Particles and moisture aren't the only contaminants of concern. Air is often overlooked, and it can also have a significant impact on lubricant health and performance. Air in oil exists in one of four distinct states or phases as outlined in Table 1 below. The impact that air can have on both the lubricant and the machine is strongly tied to the phase in which air exists in oil.

Dissolved air

The most benign form is dissolved air. Dispersed at a molecular level, mineral oils contain approximately 9% by volume of dissolved air at atmospheric pressure. While relatively harmless, dissolved air which, by definition, contains a large concentration of oxygen, is responsible for oil oxidation as hydrocarbon-based oil molecules react with nascent oxygen formed in tribochemical contacts. Pressure and temperature can affect oxidation rates since the solubility of air in oil increases as those two factors rise.

Air in oil: Four phases

Dissolved Air	Air is dispersed in the oil at the molecular level. Oil does not appear aerated and has no visible bubbles. Mineral oils will hold approximately 9% by volume at atmospheric pressure.
Entrained Air	Air is dispersed in small, visible bubbles throughout the oil, like carbon dioxide bubbles in a carbonated beverage.
Foam	Air bubbles are separated by a thin liquid (oil) film. Due to their lower density, foam tends to sit on top of the oil, similar to foam or "head" on beer. Foam can be stable or unstable.
Free Air	Free air is categorized by pockets of air trapped throughout a circulating system.

There are many causes of excess aeration and entrainment. Most common is a leaky joint in a circulating oil or hydraulic system. Often on the suction side of the oil pump or right at the pump shaft seal, air that enters the system upstream of the pump is pressurized as the oil passes through the pump causing it to initially dissolve, before reduced pressure causes air to form tiny visible bubbles.

Excess air passing through a pump can cause cavitation damage. While not as damaging as vaporous cavitation caused by the rapid condensation of water vapor or other liquids inside the pump, imploding air bubbles generate heat as well as erosive damage due to the high velocities generated as gas bubbles collapse.

Entrained air

Entrained air provides a large surface area for oxidation to occur, thereby decreasing oil life expectancy. It can also affect oil film strength if the entrained air/oil mixture enters the load zone of bearings and other oil-wetted components.

In hydraulic systems and some journal bearings, the sudden pressurization of air can result in adiabatic heating, similar to the compressive heating of diesel fuel in a diesel engine that leads to combustion. In the case of air in oil, adiabatic compression causes the surface temperature of an air bubble to increase from ambient to several thousand degrees Fahrenheit as the air bubble is pressurized from atmospheric pressure in the reservoir to several thousand psi on the discharge side of the pump. At 1800 F, even the most expensive synthetic fluid will undergo rapid carbonaceous surface decomposition on the walls of the air bubble resulting in tiny black-carbon contaminants akin to soot in diesel engine oil. This process is referred to as micro-dieseling (Figure 2).

Entrained air can also affect the bulk modulus of hydraulic fluids, which in turn affects their compressibility. When hydraulic fluids become more compressible, the hydraulic fluid may become "spongy," causing unwanted compression and lack of precision hydraulic control.

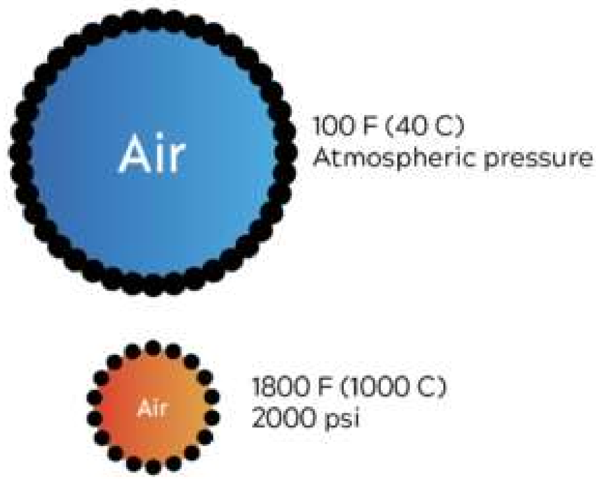
Entrained air is often caused by contamination. Small particles in the 3-to-5-micron range serve as nucleation points for air bubbles to collect. Just like a small scratch or dirt particle on the inside of a glass full of soda can cause carbon dioxide bubbles to nucleate (collect) at a specific spot on the glass wall, tiny particles can help to nucleate and disperse air throughout a fluid. This is particularly common in industries such as mining and cement where rocks are crushed as part of the process.

When oil becomes entrained with very fine air bubbles, oil fluidity can be affected. While it may seem counterintuitive, pumping a low-density gas into a fluid can cause the pumpability or fluidity of the liquid to increase, similar to whisking air into heavy cream, which can increase the kinematic viscosity due to the formation of a non-Newtonian fluid. This can prevent oil from flowing to where it needs to go to properly lubricate.

Foam

When air is present in very high concentration (often in excess of 30% by volume) and is dispersed in very fine bubbles, the air/oil mixture may form a foam. Foam has a very low density and will cause significant issues with any lubrication process that relies on gravity (think whipped cream). This can affect effectiveness of splash lubrication in gearboxes, paddles, or flingers used to disperse oil throughout a wet-sump or lifting devices such as oil slingers in process pumps.

Foam has a relatively low thermal conductivity. As such, if it collects at the top of an oil or hydraulic fluid in the top of the tank, the ability of the fluid to dissipate heat from the bulk oil will be seriously compromised. This can cause the overall oil temperature to rise, causing an increase in oil oxidation.



Micro-dieseling is caused by aeration and rapid pressure changes. It is most common in hydraulic systems and journal bearings.

Foam in oil can be stable or unstable. Guinness beer connoisseurs will be familiar with the concept of a stable foam where the sign of a well-kept stout is one that retains the "head" all the way to the bottom. Stable foam in an oil is to be avoided. Stable foam is often a result of chemical incompatibility either from the ingestion of process fluids or due to the accidental mixing of two incompatible lubricants.

Whenever a foaming or aeration issue is suspected, the oil should be tested to determine the cause of the issue. In particular, two tests should be run: ASTM D3427, which measures the ability of aerated oil to release air bubbles and ASTM D892, which measures the foaming tendency and stability. Depending on the result of these two tests, foaming and aeration can be localized to either a "mechanical" problem caused by an air leak or poor system design, e.g., a plunging return line; contamination issues; or a chemical-compatibility issue.

One common mistake in addressing sudden foaming is the temptation to add an aftermarket de-foamant additive. While these can be effective under some circumstances, de-foamants work by changing the surface tension of the air/oil interface which, at high concentrations, can result in more, not less, foaming.

Free air

In some cases, large pockets of air can form inside a circulating system in an effect called free air. Free air can prevent oil from reaching oil-wetted components, resulting in lubrication starvation or loss of hydraulic control.

Unlike particle and moisture contamination, air contamination is an insidious problem that, left unchecked, can seriously affect oil and machine health. Any increase in aeration or foaming should be addressed immediately to prevent collateral damage to components and ensure that oil health will not be compromised through thermal or oxidative failures. **EP**

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