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The Journey to Fill-for-Life:

How to (at least) Triple your Oil Life through Antioxidant Replenishment

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ABSTRACT

Sacrificial antioxidants play a critical role in determining the life and performance of turbine oils. The majority of the time when turbine oils are changed, the base stock is still healthy but the fluid is condemned because of low oxidative stability. This paper reviews how to determine if antioxidant replenishment is suitable and if so, how the life of your turbine oil can be extended. Perhaps indefinitely...

CHANGING THE PERSPECTIVE OF LUBRICANTS

The function of lubricants in machines is often compared to the blood in your body – an indispensable necessity of survival. This analogy is used in condition monitoring, as a sample of oil will not only tell you the condition of the oil but the overall health of the machine. Just like a blood sample. Filtration devices are called “kidney-loop” filters and perform “dialysis” on the oil. Optimum oil condition is as essential to a healthy machine as blood is in our bodies. When we have issues with our blood work however, a doctor doesn’t prescribe a blood exchange. Similarly, when we have challenges with our oil shouldn’t everything be done to return it to a healthy state?

In financial terms, we think of our equipment as assets. Assets have economic value with expectations of bringing the owner long-term benefits. Assets are tracked on a company’s balance sheet. Expenses on the other hand represent the cost organizations incur in order to operate and generate revenue. These are tracked on a company’s profit and loss statement. Most organizations consider their lubricants to be expenses. This thought has been carried over from our personal lives since our vehicle oil changes are considered to be one of the expenses of operating a car. Oil used in rotating equipment however, which delivers long-term benefits to organizations can rightly be considered an asset.

Considering an oil to be an asset instead of an expense is a subtle but important perspective change in lubricant management. Asset Managers go to great length to maximize the life of their investments, as should those that are managing oil programs. Anything that can be done to safely extend the life and maximize the performance of your lubricating assets can be of significant value to an organization.
Maintaining oils in a contaminant-free condition with optimum levels of additives is a strategy that many companies use to extend the life of their lubricant assets.

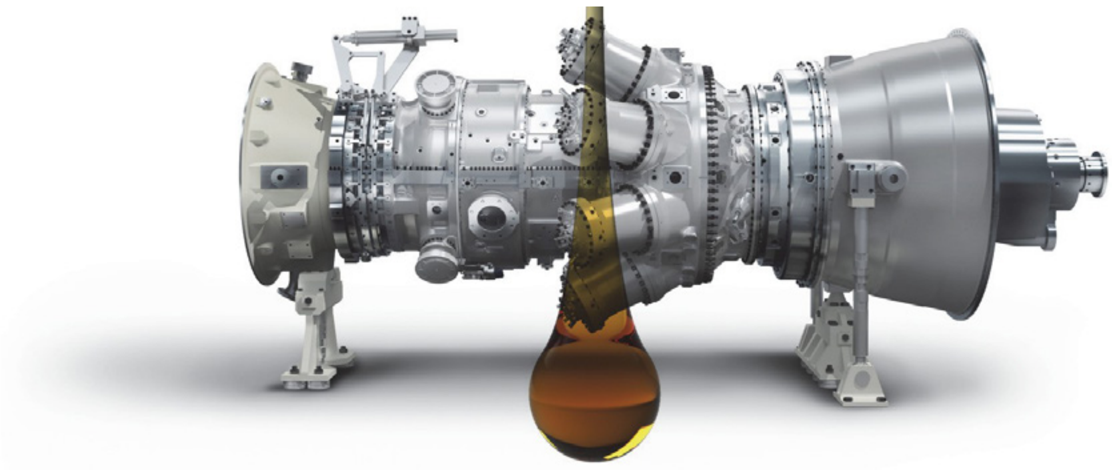

Fig. 1: The lubricants used in rotating equipment are an asset just like the machines that they are functioning in.

ANTIOXIDANT REPLENISHMENT CAN REDUCE OPERATIONAL RISK

Although lubricants play a crucial role of the operation of rotating equipment, we do not actually see them perform while they are in service. Their functionality is largely invisible to us as it cools, protects, whisks away contaminants and provides a critical layer between moving components. This is for the best. The more interaction we have with in-service lube oil, the greater the risk. Ideally, lube oils should be kept clean and dry with minimal human interaction. As Jim Fitch of Noria describes, "Of course, there are risks any time a machine is invaded by a human agency."

The first impact of oil degradation occurs at a molecular level. These chemical changes to the oil are important as it allows us to establish appropriate condition monitoring tests to monitor these changes. However, chemical changes to oil molecules don't usually result in performance problems. It's not until sufficient chemical alterations occur that physical problems start to emerge, impacting the mechanical performance of the equipment. In rotating equipment, the first physical symptom created by oil degradation is the formation of deposits. These high molecular weight deposits can cause a host of reliability challenges, such as sticking valves, elevated bearing temperatures, reduced oil flow and lower heat exchange performance.

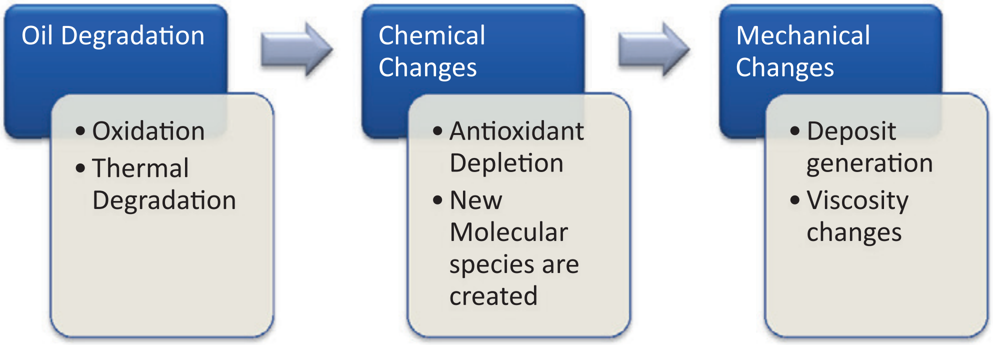

Fig. 2: The first sign of oil degradation is chemical changes to the oil which can be identified through oil analysis. Reliability challenges occur when due to the propagation of chemical changes, creating mechanical performance problems.

In well-formulated oils, the first impact of oxidation is the depletion of antioxidants. The suggested condemning limit of rust and oxidation inhibited (R&O) oils are when the antioxidants deplete to 25% of their original value.

What if an oil is not only kept clean and dry, but the depleted antioxidants are replenished on a timely basis? What if the oil degradation products and depleted additives are removed before they can accumulate and cause problems? Theoretically, it is possible to transform an in-service oil into a “fill-for- life” fluid that can last for the life of the equipment. If this is done correctly, additive replenishment removes a significant amount of the human interaction factor by eliminating oil changes and flushes.

Additive replenishment represents an opportunity to lower the risks associated with managing oils. As any turbine operator will inform you however, oil is cheap compared to the cost of their equipment. Therefore, it is critical that additive replenishment is done in a safe manner that eliminates the potential for any adverse impact to lube performance.

HOW TO ELIMINATE RISK WITH ANTIOXIDANT REPLENISHMENT

Re-inhibiting depleted additive components into lubricants is often discouraged by oil manufacturers - for valid reasons. There are multiple consequences of incorrectly adding additives back into in-service oils. In many respects, replenishing antioxidants has more variables to consider compared to formulating new lubes so it is understandable why oil manufacturers may not be comfortable with this process. In addition, additive replenishment may not be consistent with an oil manufacturer's business strategy.

Additive replenishment is also supported by industry guidelines such as ICML 55. Chapter 11 of this industry-leading document details the process for safe additive reconstruction.

However, once oil is delivered to a site and is placed into service, it becomes the plant's asset and it is up to the user to determine the optimum way of maintaining the fluid.

Oil analysis plays a critical role in determining an oil's candidacy for antioxidant replenishment. If this is done carefully, the risk of antioxidant replenishment can be eliminated. The process for performing qualification tests is summarized in Fig. 3 below.

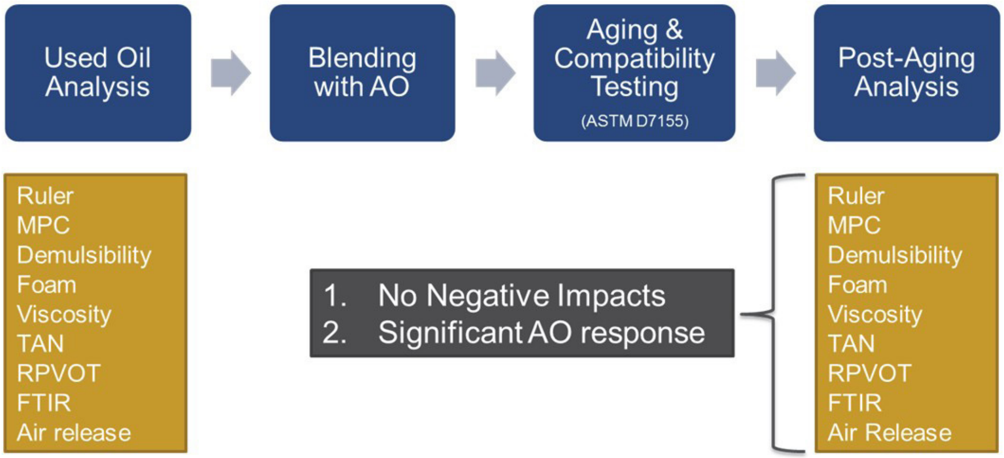

Fig. 3: An oil is considered to be qualified if no adverse effect is detected in up-front laboratory testing once antioxidants have been reintroduced to the in-service oil and if a significant antioxidant response is measured. Antioxidant compatibility is determined by ASTM D7155.

Another benefit of this qualification process is to evaluate the impact that antioxidant replenishment has on the in-service oil. If this qualification procedure is followed, the risk of introducing antioxidants to in- service oils can be eliminated. Since no two in-service oils are the same, each reservoir should be qualified independently for antioxidant replenishment.

A SUMMARY OF BOOST AO AND DECON AO TECHNOLOGIES

Boost AO and DECON AO are antioxidant concentrates custom formulated to replenish the antioxidant package of in- service oils. There are multiple recipes designed to treat various formulations of turbine and compressor oils. The antioxidant systems are solubilized in a synthetic base carrier fluid. This allows the antioxidant concentrate to be pumped directly into the reservoir of an operating turbine or compressor without the requirement of specializing blending equipment.

The side-benefits of the synthetic carrier fluid are that it imparts excellent solubility characteristics to the in-service oil improving its deposit control. This often results in a rapid, long-term reduction in MPC values.

Fig. 4 – Boost AO and DECON AO are antioxidant concentrates diluted in a specialized carrier fluid with outstanding solubility and oxidative stability properties.

DETERMINING THE PERFORMANCE OF REPLENISHED ANTIOXIDANTS

Prerequisite qualification tests are important in determining an oil's candidacy for antioxidant replenishment, however it doesn't measure the long-term performance of the freshly introduced antioxidants. Accelerated aging tests can be used to validate the depletion rate of the newly introduced antioxidants. One may also compare the rate of antioxidant depletion in treated oils versus unused oils.

Fluitec has established an accelerated aging test called the Turbine Oil Performance Prediction test. The experiment was developed to study the oxidative behavior of turbine oils in an accelerated oxidative environment. The test was designed so that samples could be analyzed throughout the test to determine the fluid time-dependent conditions. **The experiment conditions are:**

- A 350ml sample of new turbine oil is placed in a glass test cell containing a steel/copper coiled wire catalyst conforming to ASTM D5846 specification.
- The test cell, containing the turbine oil and catalyst coil, is placed into a 120 °C solid-block temperature bath.
- The sample is allowed to equilibrate to 120°C for 20min. After equilibration, dry atmospheric air is bubbled through the test oil at a rate of 3L/hr to accelerate aging throughout the duration of the test.
- The sample is subjected to these aging parameters for up to 12 weeks (± 10min.).
- After the required aging time, the oil sample is immediately decanted from the test cell and allowed to sit, undisturbed, for 4 days prior to analysis.

Weekly samples are obtained for testing. The tests performed to provide understanding of the fluid's oxidative performance are Viscosity, RPVOT, MPC (dE) and RULER. All visual observations of the experiment are also reported. Depending upon the applications, additional tests such as demulsibility, air release, foam and elemental analysis are added to the test slate.

We have used this testing protocol to estimate the performance of dozens of turbine oil formulations and have found that there is good correlation to the results of this test and field performance.

	NEW OIL		IN-SERVICE OIL		
	Before TOPP	After TOPP	As Found	After Boost AO	After TOPP
Viscosity, ASTM D445					
100°C Viscosity, cSt	5.4	5.4	5.4	5.4	5.4
40°C Viscosity, cSt	30.6	31	30.3	30	31
Viscosity Index	109	110	111	113	110
Color, ASTM D1500	1.0	7.0	6.0	6.0	8.0
TAN, ASTM D664, mg/KOH	0.09	0.15	0.14	0.13	0.15
Ruler, ASTM D6971					
% Amines	100	31	60	165	112
% Phenols	100	10	15	90	10
RPVOT, ASTM D2272, minutes	1279	550	475	812	845
Membrane Patch Colorimetry (ΔE)	1	62	11	2	55

Table 1: Comparative Test Results of New Oil and In-Service Oil with Boost AO in the TOPP aging test

The results of the TOPP aging test suggest that the rate of antioxidant depletion in the in-service oil treated with the Boost AO antioxidant system were similar compared to the unused oil in the same test. At the end of the test, the unused oil experienced a 69% reduction in amine antioxidants compared to a 53% reduction in the in-service oil treated with Boost AO. Improved deposit control characteristics can also be observed in the data. At the end of the test, new oil had an MPC of 62 versus an MPC of 55 generated by the in-service oil with Boost AO. It is interesting to note as well that the in-service oil with Boost AO had outstanding RPVOT retention properties compared to the new oil.

FIELD PERFORMANCE

Laboratory tests provide a great way of estimating field performance but cannot replace field trials. Below are the 3-year analytical results from adding Boost AO to in-service turbine oil in large frame gas turbines.

	Oct 2012, As Found	Oct 2012, After Boost AO	October 2020
RULER (Amines, %)	60	208	154%
RULER (Phenols, %)	50	216	7%
RPVOT	491	808	872
MPC	15	3	19

Table 2: Large Frame Gas Turbine #1 results of Boost AO

	Oct 2012, As Found	Oct 2012, After Boost AO	October 2020
RULER (Amines, %)	55	165	135%
RULER (Phenols, %)	20	159	6%
RPVOT	475	858	851
MPC	12	2	10

Table 3: Large Frame Gas Turbine #2 Results of Boost AO

It is important to note that this plant uses an advanced varnish mitigation system that removes oil degradation products from the oil, thereby improving the performance of the antioxidant system and extending the life of the oil.

These in-service turbine oils have 145,000 operating hours on it – quite remarkable considering the thermal and mechanical stress experienced in a gas turbine. The plant's objectives are to exceed 200,000 operating hours on its initial charge of turbine oil. With multiple antioxidant treatments, it is possible to expect the oil to last even longer than this.

ANTIOXIDANT REPLENISHMENT IS A MORE ENVIRONMENTALLY SUSTAINABLE PRACTICE

Preventing a gallon of lubricating oil from having to be refined, formulated, packaged and shipped to a site reduces the amount of green-house gas emissions by approximately 120 pounds. This may seem small when plants are measuring their green-house gas emissions in tons, however extending the life of in-service oils does have a measureable impact on a plant's sustainability initiatives.

ATTAINING FILL-FOR-LIFE OILS

Turbines and compressors are potential applications for converting their lubricant into Fill4Life™ fluids because their primary mode of degradation is oxidation. In these applications, if the antioxidants can be carefully replenished and the degradation products are controlled, Fill4Life is possible.

There are multiple other applications, such as engine oils, where the base oil undergoes significant damage during its life. Filtration or adding new chemistries to these oils will not correct base oil damage. Fill4Life oils in these applications are not possible with today's technologies.

There are many other additive chemistries used in fully formulated turbine and compressor oils, such as rust inhibitors, foam suppressants and extreme pressure additives. These additives are trickier to add to in-service oils because of the chance of over-treatment. Much more in-depth analytical work should be performed before considering the addition of these additive components.

In addition to replenishing the antioxidant system, technologies such as Fluitec's ESP varnish mitigation are important to remove oil degradation products. Combining ESP with Boost AO or DECON AO can extend the life of the antioxidants by approximately 50%.

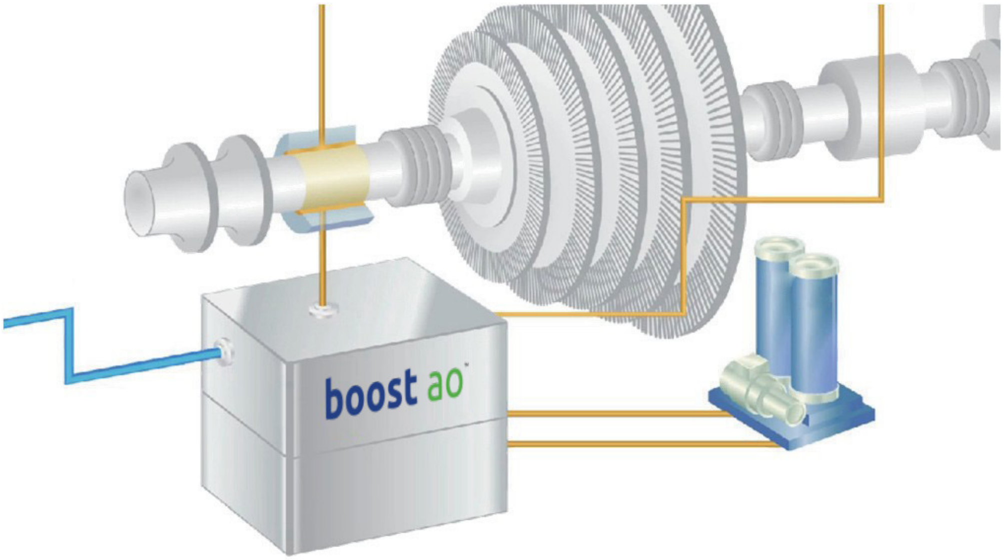

Fig. 5: Fill-for-Life Lubricants are possible in Turbine and Compressor applications.

SUMMARY

The most common failure mode of turbine and compressor oils is oxidation, resulting in antioxidant depletion. These fluids are often condemned when the antioxidant health is 25% of its new value. In situ antioxidant replenishment represents an opportunity to significantly extend the life of these fluids. This practice is supported by important industry guidelines such as ICML 55. The most important aspect of considering antioxidant replenishment is up-front laboratory testing. This allows each reservoir to be properly qualified for the addition of antioxidants and identifies any potential adverse reactions, removing risk from the process.

Antioxidant replenishment is not the solution for all lubricant applications. Turbine and compressor applications however are applications where antioxidant replenishment should be considered provided appropriate qualification has been done. Replenishing antioxidants takes a fraction of the financial resources required when replacing the turbine oil and undergoing system flushing. If done properly, the risk of replacing depleted antioxidants is lower than undergoing an oil change and flush. Extending the life of a non-renewable resource also supports a company's environmental sustainability objectives.

Reducing the cost and operational risk in an environmentally sustainable way is in line with all company's corporate objectives. With these benefits, it is easy to see how antioxidant replenishment will be the primary turbine oil maintenance strategy in the future. Ultimately, many of the oils that are currently in use in turbines and compressors have the potential to be converted to fill-for-life lubricants saving the industry millions of dollars.

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