Long-Term Results of Turbine Oil Antioxidant Replenishment at a Combined Cycle Power Plant

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1. Abstract

Significant advancements have been made in the last two decades in turbine oil formulations, utilizing superior base stocks and antioxidant chemistries. The result is that turbine oils used in even the most thermally stressful gas turbines can provide long-life and good performance provided that they are properly maintained.

Changing turbine oils is an expensive and risky endeavor. The practice is usually associated with an oil flush and consumes valuable time during outages when resources are most scarce. When the oil is emptied from the system, it is left vulnerable to foreign contaminants, cleaners and debris, risking the reliable production of power. Changing large volumes of turbine oils prematurely is not only very expensive but also is also environmentally irresponsible.

In the ideal world, turbine oils would be fill-for-life fluids, not requiring oil changes. Keeping the oil clean and dry while removing oil degradation products goes a long ways towards extending the fluid's life. However, the limiting factor are antioxidant additives. These sacrificial additives largely determine the life and performance of the product and deplete during service.

Replenishing the antioxidants in turbine oils is possible and can be safely done. An experienced formulator who is intimate with the in-service oil's antioxidant package is required to select the proper antioxidant mixture and maintain a balanced formulation. Additionally, up-front testing is required on each turbine oil reservoir to ensure full compatibility, just like if a different brand of turbine oil was being added to an in-service oil.

Salt River Project's Mesquite Power Plant produces 1250MW of power through 4 large frame gas turbines and 2 steam turbines. This paper reviews the long-term field performance of antioxidant replenishment at this facility. This case study illustrates that combining the correct contamination control technology, with a state-of-the-art oil analysis program and antioxidant replenishment can extend the life of turbine oils by at least a factor of two; possibly for the life of the plant.

Fig. 1: Mesquite Power's 1250MW power plant is located in the Arizona desert.

2. Turbine Oils are Assets

Most organizations consider lubricants to be expenses, a thought carried over from our personal lives because vehicle oil changes are considered to be one expense of owning a car. However, oil used in rotating equipment that 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 lengths to maximize the life of their investments, as should those who are managing oil programs.

Anything that can be done to safely extend the life and maximize the performance of lubricating assets provides 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.

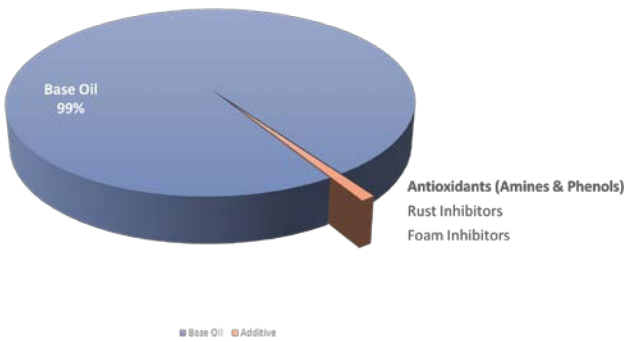

Fig. 2: Additives make up a small percentage in a turbine oil formulation, yet are key for the performance of the product.

Most commercially available turbine oils consist of 98 to 99 percent base stock and approximately 1 to 2 percent additive. This sliver of additive content plays a critical role in fluid performance, especially the antioxidants.

In the vast majority of cases, a turbine oil at the end of its life has depleted its antioxidants, but the base oil molecules are still healthy. Careful replacement of the antioxidants in in-service turbine oils can extend their useful life.

3. Turbine Oil Degradation

Oil degradation begins at the molecular level. However, chemical changes to oil molecules don't usually result in performance problems until the chemical alterations cause physical problems that impact the mechanical performance of the equipment.

In rotating equipment, the first physical symptom created by oil degradation is deposit formation. 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 rates.

In well-formulated turbine oils, the first impact of oxidation is the depletion of antioxidants. The suggested condemning limit for rust and oxidation inhibited (R&O) oils is when the antioxidant concentration drops to 25 percent of its original value.

But consider the following questions: 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. Done correctly, additive replenishment removes a significant amount of the human factor by eliminating oil changes and flushes.

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

4. Low Risk Antioxidant Replenishment

Re-inhibiting depleted additive components into lubricants is often discouraged by oil manufacturers – for good reasons. There are multiple consequences to incorrectly adding additives into in-service oils.

In many respects, replenishing antioxidants has more variables to consider compared to formulating new lubes; so, it is understandable that oil manufacturers may not be comfortable with this process. In addition, additive replenishment may not be consistent with an oil manufacturer's marketing strategy. However, once oil is delivered to a site and placed into service, it becomes the plant's asset, and it is up to the user to determine the optimum way to maintain the fluid.

Oil analysis plays a critical role in determining an oil's potential for antioxidant replenishment. One benefit of this analysis is to evaluate the impact that antioxidant replenishment has on the in-service oil. Also, since no two oils are the same, each reservoir should be qualified independently for antioxidant replenishment. Following this qualification procedure eliminates the risk of introducing antioxidants to in-service oils.

Once an oil is qualified, an antioxidant concentrate called Boost AO can be added. Boost AO concentrates are custom-formulated to replenish the antioxidant package of in-service oils. Multiple Boost AO recipes are available, designed to treat various formulations of turbine and compressor oils.

The antioxidant systems are solubilized in a synthetic base carrier fluid. This allows the concentrate to be pumped directly into the reservoir of an operating turbine or compressor without special blending equipment.

The side benefit of the synthetic carrier fluid is that it imparts excellent solubility characteristics to the in-service oil, improving its deposit control. In addition, adding Boost AO often significantly improves demulsibility and foam control.

5. Determining Candidate Turbine Oils

Qualification tests are important to determine an oil's candidacy for antioxidant replenishment; however, they don'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. The rate of antioxidant depletion in treated oils versus unused oils also can be compared.

An accelerated aging test called the Turbine Oil Performance Prediction (TOPP) test has been developed to study the 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 test conditions are beyond the scope of this article. However, samples are taken weekly and analyzed for viscosity increase and performance in the Rotating Pressure Vessel Oxidation Test, Membrane Patch Colorimetry varnish potential test and Ruler tests. All visual observations are also reported. Depending upon the application, additional tests such as demulsibility, air release, foam and elemental analysis are added to the test slate. This test has used to estimate the performance of dozens of turbine oil formulations and have found good correlation with field performance. The same test protocol has been used successfully in evaluating the performance of in-service turbine oils that have been replenished with antioxidants.

6. Experience at Mesquite Power

The initial qualification testing of Mesquite Power's in-service turbine oil determined that the fluid was suitable for antioxidant replenishment. In order to estimate the long-term performance, a TOPP test was performed on the new oil and in-service oil treated with Boost AO. The results are expressed in Table 1.

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

	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

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.

Laboratory tests provide a great way of estimating field performance but cannot replace field trials. Below are the 4-year results from adding Boost AO to Mesquite Power's GT1 and GT2 turbine oil in large frame gas turbines.

Table 2: GT1 performance of Boost AO

	Oct 2012, As Found	Oct 2012, After Boost AO	October 2016
RULER (Amines, %)	60	208	188
RULER (Phenols, %)	50	216	22
RPVOT	491	808	1114
MPC	15	3	8

Table 3: GT2 performance of Boost AO

	Oct 2012, As Found	Oct 2012, After Boost AO	October 2016
RULER (Amines, %)	55	165	135
RULER (Phenols, %)	20	159	24
RPVOT	475	858	1135
MPC	12	2	10

The RPVOT versus amine antioxidant annual depletion rates can be viewed in Fig. 3 and 4.

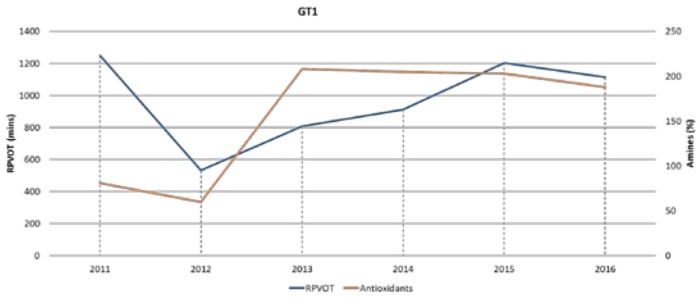

Fig. 3: The RPVOT and amine antioxidant results on GT1 show a gradual depletion in amines while the RPVOT increases over time. After 2015, the RPVOT starts to diminsh.

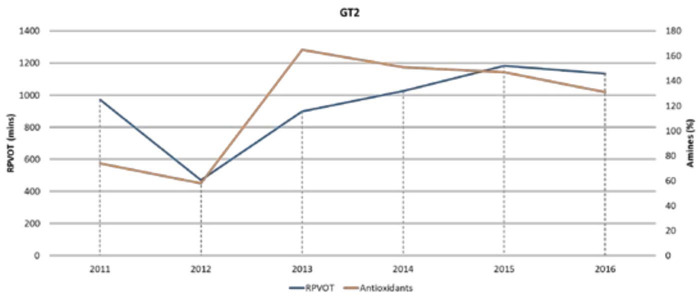

Fig. 4: The RPVOT and amine antioxidant results on GT12show a gradual depletion in amines while the RPVOT increases over time. After 2015, the RPVOT starts to diminsh.

It is interesting to note that the RPVOT values have increased over the last 4 years. This is sometimes observed and may seem counterintuitive. There are three possibilities explaining why an increase of RPVOT values may occur while an oil is in use. First, some secondary antioxidant species may increase RPVOT values. Second, phenols often have an adverse impact on the fluid's RPVOT values even though they provide extra value in protecting the amine antioxidant system and extending the life of the fluid. As those phenols deplete, an increase in RPVOT is possible. Third, the precision of the RPVOT test is quite poor for oils with values above 1,000 minutes. It is not uncommon to see RPVOT values increase as oil's age in service as a result of these phenomena.

It is also important to note that Mesquite Power 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.

7. Mesquite Power Summary

Antioxidant replenishment has proven to be successful at Mesquite Power. The plant estimates savings of about US$1M by not having to replace the turbine oil and flush their six turbines. To date, the oil has approximately 100,000 operating hours. It is the objective of the plant to attain 200,000 operating hours on the original fill of turbine oil.

8. Fill-for-Life Turbine Oils

Turbines are potential applications for converting lubricants into fill-for-life fluids because their primary mode of degradation is oxidation. Fill-for-life is possible in these applications if the antioxidants can be carefully replenished and the degradation products removed.

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. Fill-for-life is not feasible in these cases.

Many other additive chemistries are 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 potential for overtreatment. Much more in-depth analysis is needed before considering the addition of these additive components.

In summary, in-situ antioxidant replenishment represents an opportunity to significantly extend the life of turbine oils. The most important aspect to 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, helping to remove risk from the process.

Replenishing antioxidants takes a fraction of the financial resources required when replacing the turbine oil and flushing a system. If done properly, the risk of replacing depleted antioxidants is lower than performing an oil change and flush. Extending the life of a nonrenewable 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 companies’ 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 currently in use in turbines have the potential to be converted to fill-for-life lubricants, saving the industry millions of dollars.