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Type I & Type II Insulating Oils

Introduction

It is well understood that insulating oils will degrade over time due to a chemical process called oxidation. Oxidation is an unpreventable chemical chain reaction that occurs in transformers. Left unchecked, it may severely impact the insulating oil's dielectric and thermal properties. The presence of oxidative inhibitors improves the ability of insulating oils to protect against oxidative degradation and the production of undesired byproducts. To understand the reason for insulating oils with different inhibitor types and concentration levels, it is important to understand the history of refining improvements, the development of standards, and how inhibitors interrupt the oxidation pathways.

History of Mineral Oil Refining

The first patent for mineral insulating liquid was issued in 1887 and the earliest recorded instances of insulating oil use in electric transformers began in the early 1890s. At that time, the options for insulating oils were as limited as the understanding of how they were refined and would perform. The initial process of using distillation to separate raw crude oil into specific viscosity groups, often referred to as "cuts" or "feedstock" by refiners, was based on separation by boiling point. The distillation process has remained largely unchanged, while the technologies utilized to convert the feedstock into finished insulating oil have improved tremendously over time.

Throughout the first half of the 20th century, accepted refining techniques intended to convert feedstock into viable insulating oil relied on methods of clay adsorption or solvent extraction, which were intended to physically remove undesirable molecules from the feedstock. Techniques continued to improve and while some methods would produce higher-quality finished oil, they would come with the cost of poor yield or the creation of waste byproducts that required proper disposal. No singular method emerged as a way to produce large volumes of high-quality oil with sustainable prices.

Introduced to the U.S. market in the mid-1950s, hydrotreating offered a cost-effective method for producing cleaner oil, while maintaining yields and avoiding waste byproducts. Hydrotreating technology relies on high-pressure hydrogen and high temperature in the presence of specific catalysts to remove the reactive molecules containing sulfur, nitrogen and oxygen. The process also naturally converts more reactive aromatic molecules into stable naphthenic molecules. Adoption of hydrotreating was initially slow, but today it is the preferred method for transforming feedstock into insulating oil. ***Insulating oil produced by the most modern hydrotreating units is clean and stable, and can be produced both abundantly and economically.***

History of the Standards

Before Doble Engineering founder Frank Doble formed the Special Oil Committee (SOC) in 1936, which was the first group dedicated to committing themselves to the study of insulating oil, utilities were largely unsupported in their efforts to understand commercially available insulating oils.

By 1961, these oil study pioneers had paved the way for the inaugural publication of the Transformer Oil Purchase Specifications (TOPS). Intended to provide parameters for specific quantifiable characteristics of oil, Doble TOPS was initially based on uninhibited oils for two reasons: (1) natural inhibitors were prevalent because refining techniques limited the amount of naturally reactive molecules that could be removed or converted to more stable forms, and (2) Mr. Doble strongly opposed the use of synthetic additives, which he strongly felt could provide a “painted ladder,” meaning that performance characteristics of poorly refined oils couldn’t be disguised or artificially boosted with artificial inhibitors.

Following Mr. Doble’s death and the pressures created from the 1973 oil embargo, Doble TOPS was revised so that hydrotreated oils containing synthetic inhibitors could pass the tests. In 1976, the American Society for Testing Materials (ASTM) first published the reigning D3487 standard, which defines different parameters for both Type I (uninhibited) and Type II (inhibited) oils.

Oxidation

All organic material within a transformer is vulnerable to oxidative degradation and oxidation, which leads to the formation of acids and sludge. Acids and sludge are undesirable byproducts that decrease the dielectric strength of oil and negatively impact oil’s ability to effectively transfer heat. Oxidation occurs when highly reactive molecules and oxygen are present. The chemical process of oxidation is autocatalytic, meaning a chain reaction that exhibits nonlinear growth. ***Preventing oxidation is impossible; however, both natural and synthetic inhibitors can slow down the rate of oxidation in oil and improve oxidation stability.***

Oxidation Testing

Standard test methods for evaluating oxidation stability measure the resistance of mineral oils to oxidation under prescribed accelerated aging conditions. ***Test results are not intended to assess the expected life of a transformer, but rather to compare the performance of different oil samples under the same conditions.***

The ASTM D2440 method can be used to test both Type I and Type II oils. This approach involves a lengthy lab evaluation period with required measurements at 72 and 168 hours. By contrast, ASTM D2112, also known as the Rotating Pressure Vessel Test (RPVT), is a rapid test method applied to oils containing synthetic inhibitors and results are typically obtained within hours. Annually, Doble performs these tests on both Type I and Type II oils for inclusion in their TOPS report.

Role of Antioxidants

An antioxidant is a compound that reduces the oxidation of other compounds. In transformer oil, antioxidants extend the life of the oil by interrupting the propagation of the free-radical process of oxidation. The ability of inhibitors to delay the process is limited because when inhibitors react, they are expended and their role as an antioxidant ends. While natural inhibitors are unable to be replaced after they have been expended, synthetic inhibitor levels can be monitored and replenished periodically. ***As inhibitor concentration declines over time, the rate of oxidation and oil degradation increases.***

Natural Inhibitors

Natural inhibitors are molecules already present in the oil that have molecular structures favorable for interrupting the oxidation chain reaction. Compounds containing sulfur are considered strong natural inhibitors. Hydrotreated oils experience lower concentrations of natural inhibitors which easily cause them to convert into less reactive and more stable molecules during hydrotreatment. Most of the oil’s characteristics may be restored during the reclaiming process; however, natural inhibitors are irreplaceable once they react.

Synthetic Inhibitors

Synthetic inhibitors are additives mixed with insulating oil after hydrotreatment before oil is put into service. There are a small number of antioxidants that perform well within insulating oils. The most commonly used synthetic inhibitor is Butylated Hydroxytoluene **(BHT)** which is also known as **DBPC** (2,6–di-tert-butyl-p-cresol). A similar but less commonly used inhibitor is **DBP** (2,6–di-tert-butyl phenol).

Other synthetic inhibitors have been used with refined oils in the past and have since been rejected for varied reasons. For example, dibenzyl disulfide **(DBDS),** a synthetic inhibitor that was used in the late 1990s to the early 2000s by some refiners, turned out to be the source of corrosive sulfur inside the transformer. The heat of the transformer caused the DBDS compound to break down and produce corrosive sulfur.

Inhibitor Testing

The ASTM test method D2668 calculates the weight percent of synthetic inhibitors in new and used oils. According to ASTM definitions, Type I oil’s synthetic inhibitor level may range between 0.0% and 0.08% of its total weight. Type II oil’s inhibitor value may range between 0.0% and 0.30% of its total weight. ***Synthetic inhibitor levels below 0.08% may be classified as Type II oil; therefore users are encouraged to take note of inhibitor levels prior to approving insulating oils.***

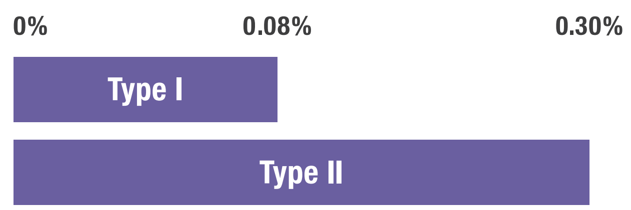

Figure 1.
ASTM classifications for added inhibitor content (% by mass)

Conclusion

Oxidation will develop in all transformers over time regardless of the insulating oil present. Oils may differ in what types of inhibitors are present and how those concentration levels will change over time, but they all serve to interfere with and slow the oxidation reaction.

While modern severely hydrotreated oil is void of natural inhibitors, the clean and stable oil offers an excellent platform for the synthetic inhibitor to provide a superior oxidative response and maximize the resistance to oil degradation. Test limits for Type II oils are more stringent as a result, indicating the improved performance of the oil.

In response to global market demand and consumer preferences, leading global refineries increasingly produce and promote inhibited oils but do continue to offer uninhibited products to foreign markets where they are used in distribution and some small power transformers.

We strongly encourage those involved with the selection of insulating oil to consult with a trusted transformer manufacturer to identify the best solutions for their applications.