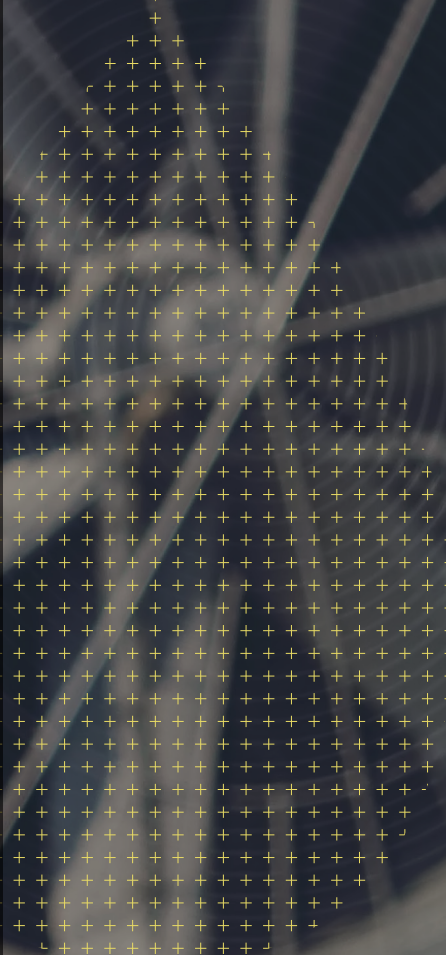




**Randy D. Stebbins**, 70 of North Canton, Ohio passed away suddenly on Thursday, December 8th, 2022. He was the loving husband of Linda for 39 years, adored father of Shannon (Josh) Howell and beloved Papa of his granddaughter Riley and grandson Teigen. He is the brother of Wayne (Connie) Stebbins, Danny Stebbins, the late Richard Stebbins (Evelyn) and Roger Stebbins; brother-in-law to Mary Lou and Joseph Simitz, the late Patricia and Wilfred (Butch) Stoehr, and the late Joan and Warren McGuire. He is also survived by many nieces and nephews, great nieces and nephews and great-great nieces and nephews. Randy was born in Barrington, Illinois to the late Riley and Opal Juanita Stebbins on July 6th, 1952. He attended Northern Illinois University in DeKalb earning his Bachelor of Science degree in Chemistry and Physics. He attended the University of Chicago receiving his MBA in Economics and Finance. Randy was employed by S.D. Myers for 29 years first as Laboratory Mgr., appointed Lead Instructor and Technical Advisor for Transformer Maintenance Inc. (EPIQ) before retiring in 2020. In 2021, Randy formed R.D. Stebbins Consulting, LLC. and worked as an Independent Contractor for S.D. Myers. Randy traveled many miles in his position as Instructor over the years to many foreign and domestic locations and most recently again to Australia in October. He traveled to all 50 states doing the work he loved alongside instructors and coworkers that are cherished friends.



# Load Tap Changers: Testing Insulating Liquids

by **Randy Stebbins**  
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Photo: Shutterstock

*Editor's note:*

*When I came across this article, first published years ago, written by Randy Stebbins, I realized what an icon he was in our industry, as the Lab Manager and then Training Manager for SDMyers on transformer oil testing, diagnostics and analysis. He taught me more about transformer reliability without ever mentioning the word reliability.*

*Randy was also an amazing trainer, in that there was not a topic he could not discuss in detail when it came to oil analysis. I remember sitting in for one of his classes and detailed questions, one after another, were all something he could address and do with excellence. Practitioners loved his classes. Sadly, Randy retired and then passed away, but his legacy lives on and I am proud that we at APC Media get to share in that legacy.*

*Enjoy!*

Load Tap Changers (LTCs) are a common feature on many power transformers, designed to automatically change the transformer's tap position to the desired level. This paper examines the cost-effective and widely recognized maintenance strategy of fluid testing, as outlined by NFPA 70B. It explores the insights fluid testing can provide and highlights key field repairs associated with LTC maintenance. The fluid evaluation process involves several diagnostic tests that help determine the condition of the LTC and inform maintenance actions. A critical factor influencing LTC reliability is liquid oxidation and aging, which can significantly impact performance over time.

## HOW DOES OIL AGE IN AN LTC?

Testing the oil in load tap changers provides valuable information on the unit's operation. Monitoring conditions between preventive maintenance inspections is critical in helping prevent expensive maintenance problems and unplanned outages. The aging mechanisms are considerably different from oil in other electrical equipment types. Understanding this aging process reveals some of the challenges of maintaining LTCs, but it also presents some opportunities for improving the effectiveness of the overall maintenance program.

The interior of an arc-in-oil LTC is a very energetic environment. The oil usually has a relatively high level of dissolved oxygen content since most LTCs are free-breathing. There are two main types of LTCs: the vacuum-interrupter type and the arc-in-oil type.

With the vacuum-interrupter type, the LTC liquid should not have

appreciable combustible gases but still has the need for regular liquid testing and maintenance intervals.

There are frequent discharges (arcing) for the arc-in oil type as taps change while under load. Conditions are harsher compared to those inside other types of electrical equipment, which causes one of the aging mechanisms in LTCs - in this environment, oil oxidizes more rapidly than in a milder environment, such as inside a sealed and properly maintained transformer. However, unlike oil in transformers, there is a second aging mechanism for oil in LTCs that affects the operation of the device, usually long before oxidation proceeds far enough to cause any serious degradation of the oil's performance.

As oil ages in a load tap changer, it polymerizes, forming a gummy, varnish-like film over the contacts and mechanism. Viewed with the naked eye, this smooth coating is generally very dark and often mistaken as a carbon deposit or evidence of coking.

The smooth appearance is unlike the typical pebbly surface of a coke deposit after it forms in an electrical device. The surfaces of the contacts, that have been wiped clean and show up as bright areas of relatively clean conductor.

This film is both mechanically and electrically resistive. As filming becomes more advanced, it can adversely affect the efficient operation of the device. If the contacts have a heavy layer of film on them, the oil's quenching becomes less effective, so the arc is sustained longer on the contact surface. This may cause hot-spot overheating of the contacts and result in premature wear. In extreme cases, overheating of the contacts may lead to contact failure.

Filming also occurs over the mechanism of the load tap changer, which provides additional resistance to mechanical movement within the device. As a result, the LTC needs to work harder to change taps. It takes longer for tap changes to be accomplished, further extending the

Although oxidation is not generally the most critical aging mechanism of the oil in an LTC, oxidized oil forms film more rapidly than clean, unoxidized oil. Since there is less concern of damage to solid insulation by oil oxidation products in an LTC, the industry has tended to pay less attention to oxidative liquid aging.

The oil inside a Load Tap Changer (LTC) undergoes unique aging processes that can significantly impact the performance of the equipment. Unlike oil in a transformer, which primarily suffers from oxidation, oil in an LTC also forms polymerized films that coat the contacts and internal mechanisms.

Testing the oil in load tap changers provides valuable information concerning whether the unit may have conditions that can create filming at a rate that may compromise the unit's operation. Liquid screen tests, moisture content, and dissolved gas analysis are used to monitor conditions between preventive maintenance inspections and what abnormal results from these tests may indicate.

contacts' arcing. This additional work generally increases the operating temperature within the device due to mechanical resistance. Overheating can become more severe in cases where the mechanism is filmed extensively. Delays in completing tap changes may also cause resistors in the LTC to experience overheating. In extreme cases, the mechanism's operation may be compromised to the point where there is an increased risk of device failure due to binding.

Overheating of the contacts and of the mechanism may also lead to coking. Coking is destructive within an LTC as the hard deposits inhibit proper operation and may lead to contact failure. Also, coke particles are very abrasive to the contact surfaces and may cause premature wear.

Particles from any source, including those caused by the normal wiping of the filmed surfaces during the device's operation, may be incorporated into the film as it forms. These particles are usually very abrasive and generally add mechanical resistance to the mechanism's proper operation.

### **WHAT CAUSES ACCELERATED FILMING IN AN LTC?**

Although oxidation is not generally the most critical aging mechanism of the oil in an LTC, oxidized oil forms film more rapidly than clean, unoxidized oil. Since there is less concern of damage to solid insulation by oil oxidation products in an LTC, the industry has tended to pay less attention to oxidative liquid aging. Most owners use guideline values for acid and interfacial tension that are much less restrictive when evaluating oil in an LTC than those they use for oil in transformers. Our experience indicates that a better strategy is to use the same acceptable, questionable, and unacceptable ranges for values used for in-service oil for transformers. However, recommendations from these values and ranges are interpreted differently than those for transformer oil. In the

case of LTCs, replacing or reclaiming the oil is recommended when the values for acid or IFT become unacceptable.

Just as higher moisture content causes oxidative aging of transformer oil to progress more rapidly, elevated moisture content in LTC oil will cause faster filming of the contacts and mechanism. This process is not as clearly defined or documented with LTCs as the effects of higher moisture on the aging of oil in transformers. However, our experience from analyzing particles and filming compounds on oil from load tap changers and reviews conducted during preventive maintenance of such devices confirms a correlation between moisture and filming. Furthermore, high moisture in an LTC also leads to reduced dielectric strength of the oil and moisture tracking within the device. Unacceptable moisture levels indicate an unacceptable risk of tracking and even dielectric failure of the oil. The values we use to define unacceptable moisture levels correspond to those where encountering runaway filming in the device is expected.

As previously mentioned, film wears off the contacts during the normal operation of the LTC. The movement of the contacts across each other, arcing at the contact surface, and arcing in the oil also produce other types of metallic and non-metallic particles. These particles are incorporated into the new film. If the oil has an unusually high number of particles, or if the particles are unusually large, the new film forms more quickly. Incorporating the existing suspended particles into film as it forms in an LTC can be of particular concern if there are large numbers of metallic or carbon particles. These are much more abrasive than the other non-metallic particles generally found in load tap changers. When film forms on the contact surfaces and incorporates metal and carbon particles, normal operation of the device can erode

those contacts at an accelerated rate. Similarly, film incorporating such particles is more mechanically resistive on moving parts of the mechanism, having a further detrimental effect on the efficient mechanical operation of the LTC.

Incompatible compounds in the insulating oil may also greatly accelerate filming in an LTC. One frequent source of such incompatible compounds is using solvents as cleaners during LTC maintenance and inspection to clean the contacts and mechanism. Only hot mineral oil dielectric fluid should be used for this application. Any other material, such as brake cleaner, spot remover, chlorinated or aromatic solvents, or paint or lacquer thinner, may make film removal easier for the current project; however, using these solvents will greatly increase the rate at which the film forms in the future.

Further, films from incompatible compounds may frequently be more difficult to remove. So, the short-term gain from using such cleaners and solvents is far outweighed by the more frequent need to clean the LTC and the greater difficulty in cleaning the device in the future. If an LTC exhibits an unusually severe filming tendency, trouble-shooting oil tests may be performed to help identify the cause. Our experience is that inappropriate cleaning materials account for many of these types of problems.

Testing the oil in load tap changers provides valuable information concerning whether the unit may have conditions that can create filming at a rate that may compromise the unit's operation. These oil tests also indicate other conditions that may require preventive maintenance before normal or planned maintenance. Liquid screen tests, moisture content, and dissolved gas analysis are used to monitor conditions between preventive maintenance inspections and what abnormal results from these tests may indicate.

## LIQUID SCREEN TESTS, MOISTURE CONTENT AND DISSOLVED GAS ANALYSIS

The Liquid Screen test package for LTCs includes the same analyses performed in a Liquid Screen test package for transformers, and diagnostics are conducted for similar reasons. Neutralization number (acid number) and interfacial tension (IFT) are both accurate, direct measures of oil oxidation. The acid number increases while IFT decreases as the oil ages and oxidizes. As discussed earlier, when these values are within the ranges that are classified as unacceptable in a load tap changer, the oil has oxidized to the point where filming starts to advance much more rapidly. The D877 and D1816 Dielectric Breakdown Voltage tests can be valuable tests to detect several contaminants such as very high moisture and particles. Since oil changes in color as it ages, this is usually not quantitative enough to be of diagnostic value on its own. Visual examination for appearance characteristics is much more helpful in evaluating contamination by free water, sediment, and heavily carbonized oil. As with the acid number and IFT, an unacceptable classification for appearance or sediment also indicates a need for corrective action.

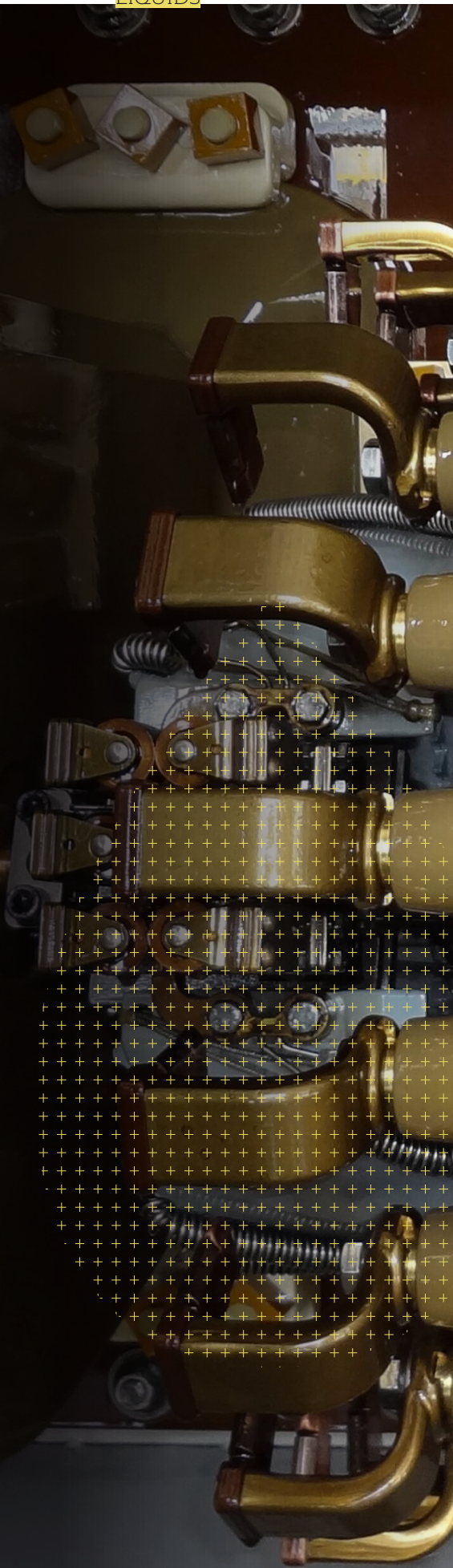
Testing for moisture content by coulometric Karl Fischer titration is essential for monitoring the water content of the oil within the load tap changer. Moisture values that are classified as unacceptable indicate a high enough quantity of moisture present to greatly accelerate the filming of the oil onto the contacts and mechanism.


In addition, unacceptable moisture content greatly increases the risks of electrical tracking and even dielectric failure within the device. Unlike typical moisture parameters in transformers—where moisture

saturation in the oil and moisture content in the solid insulation present a concern—in LTCs moisture measured simply in parts per million (ppm) is more telling. Moisture content greater than 35 ppm, but less than 60 ppm, warrants increased monitoring via shorter-interval moisture testing (six months). Moisture content confirmed to be 60 ppm or greater indicates need to perform maintenance and reduce the hazards that high moisture presents.

Dissolved Gas Analysis (DGA) has been a valuable tool for evaluating the condition and operation of transformers since the mid-1970s. Using this analysis to evaluate LTCs has a shorter history but is of considerable value for indicating needs for inspection and maintenance. The generation of acetylene and hydrogen is expected as an arc-in-oil load tap changer operates normally. As the LTC changes tap positions, arcs between contacts occur and are quenched by the insulating liquid. These transient arcs form acetylene and hydrogen. Many LTCs have breathers to allow for the escape of the hydrogen—which is not very soluble in insulating oil—to prevent the buildup of explosive conditions in the gas space of the device. If the arc is being quenched efficiently, DGA will indicate increasing values for acetylene. Increases of the other gases should be smaller if the LTC is operating normally.

Abnormal operation of an LTC will cause the unit to have abnormal gassing. The gases of concern are ethylene, ethane, and methane. Ethylene is formed in insulating oil within an energized LTC by temperatures exceeding 300°C, indicating a localized hot spot from sustained arcing and a potential maintenance issue. Under normal conditions—where typical arcing between contacts is occurring and is being quenched promptly—much





more acetylene than ethylene will be dissolved in the oil. If the arc is sustained for an extended period, the resulting hot spot will generate additional ethylene, and the relative amount of ethylene compared to acetylene will increase. Other abnormal conditions that may cause the generation of ethylene include contacts being poorly aligned so that a smaller surface area on the contact is used to conduct the rated current of the device, resistors (in resistive type LTCs) being overloaded or overheated over their design parameters, and coke formation. Alignment and timing go hand in hand to reduce wear and arcing.

Ethane and methane are also formed under abnormal conditions. When the contacts are overheated by hot spots, ethylene, ethane, and methane are generated and dissolved in the oil in unusually high quantities. Another key factor is the filming of the mechanism of the load tap changer, which causes it to work mechanically harder to continue changing taps. Increased heat is the inevitable result of the additional friction introduced by the buildup of film on the mechanism. Analysis of dissolved gases in oil from LTCs is well established, and industry groups such as IEEE have established guidelines for the interpretation of the gas profiles. Standardizing these guidelines has been challenging because of a lack of universal patterns for abnormal gassing. Different manufacturers—and even different models for the same manufacturer—sometimes have widely differing gas profiles that could all be legitimately characterized as normal. We have assembled an extensive database of test results from different models of load tap changers and have developed a system for diagnosing the conditions within these devices. We have contributed this database to leading industry groups to aid in the collective effort of consolidating technical guidance for LTC owners.

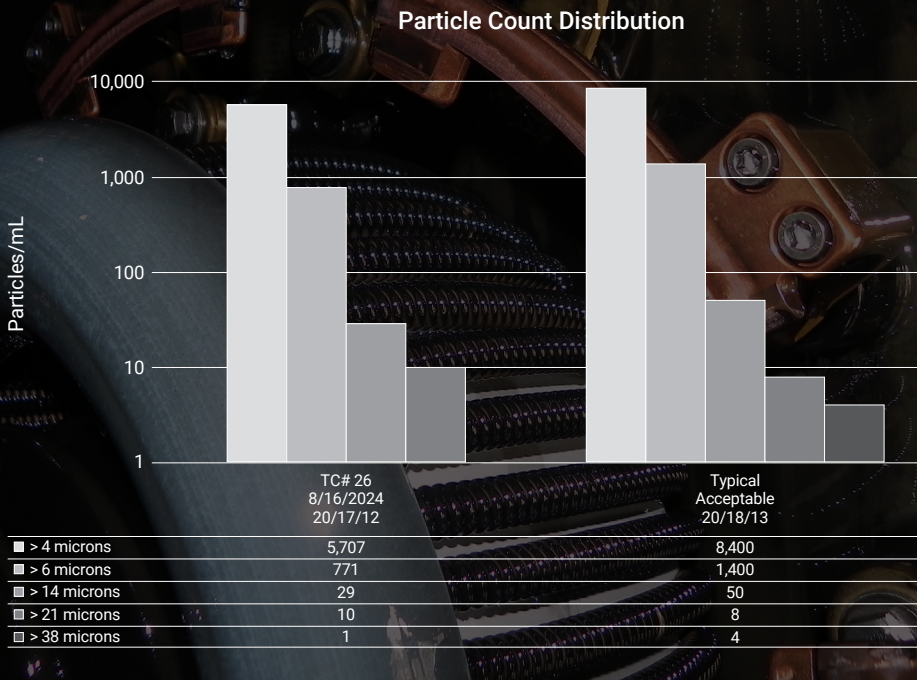
In summary, routine analysis for the Liquid Screen Tests is performed (1) to identify immediately hazardous conditions arising from contamination and other key problems and (2) to evaluate whether the potential for rapidly worsening filming exists due to the condition of the service-aged oil. Moisture content determination evaluates the risks for accelerated filming and, thus, increased risks of dielectric failure or moisture tracking. Dissolved Gas Analysis helps evaluate whether overheating of the contacts or the mechanism indicates abnormal operation. Abnormal results for any of these tests may indicate a need for preventive maintenance and an internal device inspection.

#### **PARTICLE COUNT DISTRIBUTION**

We have addressed some of the tests that are routinely performed on insulating liquid from load tap changers: Liquid Screen, Moisture Content, and Dissolved Gas Analysis. Routine testing for the particles found in the oil also provides critically important information. Particles and Filming Compounds Analysis includes two separate analyses: particle count distribution and analytical ferrography. This segment focuses on particle count distribution for load tap changer insulating liquid samples.

Particle counting—total count and size distribution—is performed according to ASTM Standard Method D6786. The automatic particle counter optically senses and then analyzes a test specimen of insulating liquid. It counts and assigns standard sizes to a representative group of particles. The total number of each size in each volume of oil is calculated, and the values are reported as size distribution in particles per milliliter for each size range. Older or non-standard methods may have reported particles per 10 mL or 100 mL, and this change in the reporting method must be considered when evaluating history.

Particle count distribution results are reported graphically, like this example:



The graphic above is from analyzing an oil sample from a load tap changer. Below the TC identification and sample draw date, the results are characterized by a rating of the distribution according to ISO Method 4406. Although developed primarily for applications involving lubricating oils, the ISO ratings can be easily adapted for insulating oil applications and are discussed in the ASTM standard method. The rating's first (and largest) value is based on the number of particles per milliliter larger than 4  $\mu\text{m}$  ( $\mu\text{m}$  is listed as microns in the data table). Similarly, the middle value is based on the number of particles per milliliter larger than 6  $\mu\text{m}$ , and the last (and smallest) value is based on the number of particles per milliliter larger than 14  $\mu\text{m}$ .

The right part of the graphic indicates what a typical particle count distribution for a load tap changer should be—one that is considered acceptable for an arc-in-oil device. If the values for > 6 microns and > 14 microns are within the appropriate typical ranges, elevated or high values for > 4 microns are usually of little concern. However, high values for the larger size ranges, > 21 microns and > 38 microns, are generally of greater

concern. In addition to this base outline, changes since the last analysis and trends upward also affect the interpretation of particle count data.

The most significant source of particles suspended in the insulating oil of an LTC is the filming of the oil. The film accumulates over time as deposits on the contact surfaces. Under normal operation of the LTC, this deposited material is wiped off and sent into the oil as small particles. These tiny particles stay suspended in the oil until they are reincorporated into a new film as they form in the device.

Another significant source of particles in an LTC is carbon formation in the oil due to the natural arcing that occurs as the contacts change position. Carbon particles are also incorporated into film as the insulating oil ages in the device. During normal operation of an LTC, these small film and carbon particles will be noted primarily in the > 4 microns and > 6 microns values and will generally not cause those values to become excessively high. As filming becomes more advanced, or if the LTC operates much more frequently than usual, values for these two smaller ranges increase. More significantly, much greater values for the larger size

ranges are also noted when filming becomes more advanced.

Our laboratory uses our experience and database to evaluate particle count results from insulating oil in electrical equipment. These results were compared to actual field data gathered during LTC servicing for many years. Ranges have been established that we consider typical and acceptable based on particle counts by size range.

Particle count distribution provides valuable information concerning the condition of a load tap changer, particularly the rate at which film is both forming and subsequently being disrupted during the operation of the device. There is also a second powerful tool for characterizing particles found in a load tap changer—analytical ferrography—that describes the composition, and sources of the particles found.

Ferrography is an advanced diagnostic technique used to analyze wear particles suspended in oil. Ferrography can aid in identifying mechanical wear, contamination, and overheating by characterizing particles from the oil, and is interpreted along with particle count data to evaluate conditions inside the LTC and inform maintenance responses.

*Remember, the oil inside a Load Tap Changer (LTC) undergoes unique aging processes that can significantly impact the performance of the equipment. Unlike oil in a transformer, which primarily suffers from oxidation, oil in an LTC also forms polymerized films that coat the contacts and internal mechanisms. These films can introduce mechanical and electrical resistance, leading to overheating and premature wear of the contacts. The continuous operation under these conditions not only affects the efficiency of the arc quenching but also creates additional stress on the mechanical components, potentially causing failures. Oxidation leads to several conditions seen in liquid tests that are used to diagnose maintenance needs. The liquid tests lead to extended life and optimized reliability when coupled with regular inspections and following manufacturer recommendations.*