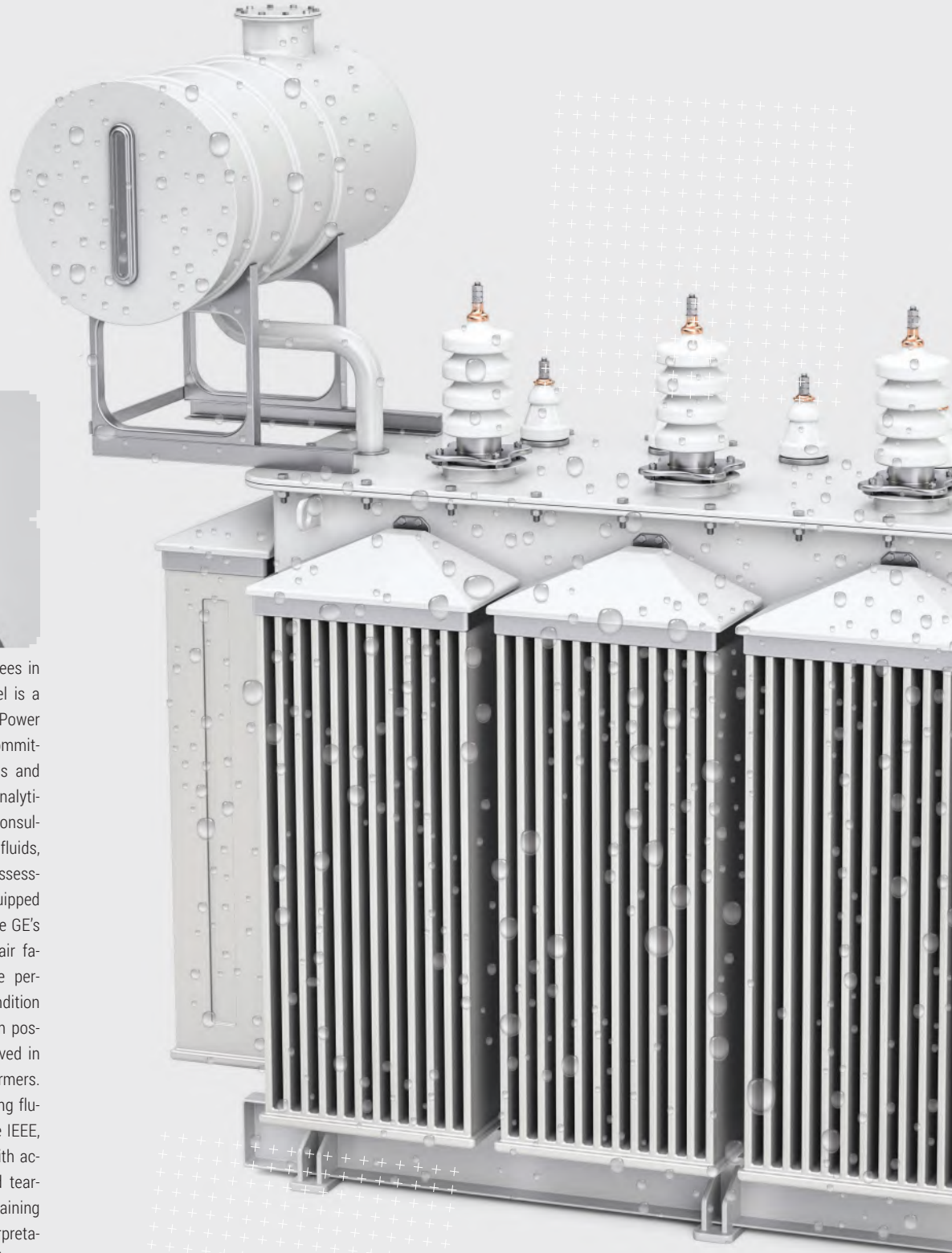


Moisture in New and In-Service Transformers

by **Mel Wright**



Melvin (Mel) Wright holds BSc degrees in Chemistry and Forensic Science. Mel is a current and past member of IEEE Power and Energy Society and ASTM committee D27 (Electrical Insulating Liquids and Gases). He has 40+ years as an analytical chemist, laboratory manager, consultant and educator on transformer fluids, fault identifications and condition assessment. Mel designed, built, and equipped the transformer fluid laboratory in the GE's Denver transformer service and repair facility (the Denver LIL) in 1980. He performed fluid testing, provided condition assessments, consulted engineers on possible fault conditions, and was involved in many forensic teardowns of transformers. He gained in-depth knowledge in using fluid testing and other data to compare IEEE, IEC and other international guides with actual faults found during testing and teardowns. Mel provides clients with training on fluid sampling, diagnostic interpretation of laboratory tests and on-line oil monitor data. Mel provides intensive training on interpreting DGA, Furans, Fluid Quality test data with transformer operating history in creating "Valid and Actionable Condition Assessments" of transformers.



This is not the typical water in oil discussion about limits, percent saturations and so on. The goal of this article is to give transformer maintenance personnel some points to ponder when dealing with both dissolved and free water in mineral oil transformers. I'll present some real-world experiences and discuss some visual aids or experiments to better understand the gross interactions of water in mineral oil dielectric fluids.

The vast majority of water issues that develop in in-service transformers are due to maintenance oversight or errors.



Never trust that "new oil" means that the fluid, as delivered, meets specifications. Test and verify!

Transformer manufacturers and the producers of mineral oil dielectric fluids go to great efforts to ensure their products are as free of water as possible. There are many tests performed to validate that both the transformer and the fluid meets ASTM, IEEE and IEC specifications. The question becomes: How does water get into transformers compromising both the fluid and the cellulose insulation? Let's review some real-world examples.

How does water get into new or in-service transformers?

Transport Tankers

Over the years numerous transformers have been filled on-site with "new oil" with high levels of dissolved water and a few with free water. The source was found to be free water in the tanker compartments. Neither the supplier or the commissioning team were aware that the transporter's procedures for providing a "clean tanker" involved steam cleaning the interior tanker walls to removed gasoline, diesel fuel or other petroleum products previously transported.

The fluid from the supplier's tanks were tested and found to be excellent in quality, so the commissioning personnel did not question the quality of the oil delivered in the tanker. In addition, during this time period, several transformer service facilities' new oil storage tanks were contaminated. Not until the utility performed annual oil testing was the high dissolved water discovered. Widespread testing of transformers, storage tanks, pumping equipment and hoses finally led to the source of the water. Needless to say, remediation costs were very high. Examination of the tankers revealed that each of the three tanker compartments could have between 5 to 20 gallons of free water. Oils with this amount of water had been pumped into storage tanks and transformers with each shipment.

Lesson:

NEVER TRUST oil in tankers.





While it is true that water does not magically appear in transformers, we also know that there are cases where water can increase from circumstances other than leaks.

Compromised Gaskets

Several N2 sealed transformers showed trending increases in dissolved water, and DGA tests showed excessive O2 content. Inspection of the transformer found the headspace pressure gauge reading zero psi, confirming that the N2 blank was compromised. Improperly installed and damaged gaskets on the top allowed rainwater and snow melt to enter the unit. Drops of free water were found hanging from under the top plate, while drops or puddles of water were found on some of the horizontal surfaces and at the bottom. The transformers were sent to a repair facility for untanking, testing of windings, oven drying of the core and coils and tank cleaning.

Maintenance Errors

A common error in maintaining the oil preservation system of free breathing transformers, especially in hot, humid climates, is maintaining the silica gel media. Missing canisters, saturated silica gel media, especially in tropical areas is common. Some of these units have large amounts of free water in the bottom of the



tank, high dissolved water and highly oxidized oils. Fortunately, most are lightly loaded (less than 40%) and thus the risk of cellulose insulation failure from water and oxidation degradation is low. However, as nearby infrastructures expand and the loading increases, so does the failure rate. There are many other operator and servicing errors that can introduce water into transformers in addition to these common ones.

Interactions of Water and Oil

Water is a unique fluid – a small molecule with interesting interactions due to its polar nature. Oil, on the other hand, is composed of hundreds of various, large, non-polar molecules which are devoid of attraction to each other or water. This hydrophobic (water hating) nature is one of many reasons that mineral oil dielectric is the universal fluid of choice. However, oil that is highly contaminated with polar oxidation products (identified by Fluid Quality tests results: very low IFT, high neutralization number and dark color) will be able to hold large amounts of dissolved water.

Filtration to remove dissolved water

Some interesting issues have occurred as a result of filtering units high in dissolved water and having free water using cellulose filters. Here are a few examples of how corrective actions to remove water can go bad.

Not Understanding Changes in Solubility with Fluid Temperature

The process of using cellulose cartridges to remove dissolved water from oils requires a basic understanding of the changing affinity of water between the fluid and the cellulose as the temperature of the fluid changes. Heating oil as it

a number of ways to achieve this before passing the oil through the cellulose filters. The cooler the oil, the lower the solubility of the water in oil, thus increasing absorption and removal by the filters. Think of it in this way, the ratio of absorption of water by the filters increases compared to the decreasing water holding capacity of cooler oil. Hot oil holds more water, which is perfect for extraction from the tank; however, hot oil can greatly reduce the exchange ratio of water from the oil into the filters. In some cases, if the filters are nearing saturation and the oil is hot, there can be a zero exchange or even a transfer of water from the filters to the oil.

Awareness of the issues presented in this article, by conscientious samplers and maintenance personnel, are critical to maintaining transformers with acceptable levels of moisture, based on industry standards.

Rush to Complete Filtration

Time constraints at facilities commissioning large numbers of distribution class units, with filtration end points determined by the volume filtered, might force the operators to speed up the process, against good practices, by increasing the filtration flow rate. Increasing the flow rate will increase the head pressure on the filters. If the filters absorb a lot of water, the resistance increases reducing the flow rate and increases the pressure on the filters. In some cases, the point is reached where water saturated cellulose fibers start breaking off and enter the transformer. It is easy to determine when this happens by testing the oil for dielectric strength. The series of 5 or 10 tests (voltage flow) on the sample will vary drastically from high to low. High dielectric breakdown results for the oil, but when water saturated fiber floats between the electrodes, a low dielectric breakdown occurs. The labs will report "a failed standard deviation result" per ASTM D1816 as well as, in this case, each of the 5 or 10 test results, the mean. The maintenance personnel receiving a report like this should evaluate the results, consider resampling for confirmation. If similar results are obtained on the resample, review maintenance records to determine if the source can be determined or what actions to take.

Cartridge style cellulose filter is used to remove dissolved water in oil



goes into the transformer increases the solubility of water in the oil, facilitating the removal of water. However, pulling this oil directly from the tank and passing this hot oil directly through the filters can be harmful to the process. Hot oil may have a higher affinity for the water than the cellulose filters, depending on temperature, the dissolved water content of the oil and the amount of water that has built up in the filters. When possible, the oil should be allowed to cool, and there are

End Point for Filtration

If testing for dissolved water is not available, a common practice is to end filtration based on filtering a set multiple volume of the main tank. For the transformer holding 1,000 gallons of oil the filtration process would stop after 5,000 gallons passed through the filters. If the units did not have free water in the bottom of the tank, this was found to be a reliable filtration end point with the oil meeting dissolved water limits.

Transformers with Free Water

Free water will settle to the bottom of the tank. Sample/fill/drain valves are from 1 to 6 inches above the bottom of the tank. Thus, free water could be that depth and not be detected in a type fluid sample. If the visual examination of the previous oil sample did not identify the existence of free water, it is unlikely that anyone is aware of the large reservoir of water below the sample port. Filtration, even using hot vacuum, will not remove the majority of the water. The filtered oil above it will meet the desired specification for dissolve water content after filtering, but the reservoir of free water will still exist on the tank bottom. Due to the core and coil support structure at the bottom of the tank, pools of free water can be trapped in areas so that even if you could tilt the unit, you would not be able to pump out or solvate the water from the unit. If six months after filtration to remove water the oil shows increasing trends of high dissolved water, you can be fairly confident that the source is this undetected reservoir of free water below the sample/drain valve, trapped at the bottom of the tank.

Decision time for the transformer owner: leave it and filter to remove dissolved water every couple of years or address a permanent solution.

Conclusions

New transformers and fluids are as dry as technology allows when shipped. Water should never be an issue in operating transformers if commissioned correctly. Never trust that "new" means that the fluid, as delivered, meets specifications. Test and verify!

Always flush fluid pumps, hoses and filtration units with three times the total "dead" volume of the equipment. Capture the last flush fluid and test to validate that the quality of the oil did not change. Only after this pumping filling equipment validation test should you use it to fill or top off a transformer. The vast majority of water issues that develop in in-service transformers are due to maintenance oversight or errors. Examples are water ingress via damaged gaskets, compromised fluid preservation system, damaged conservator tanks, bladders, etc. While it is true that water does not magically appear in transformers, we also know that there are cases where water can increase from circumstances other than leaks. Awareness of the issues presented in this article, by conscientious samplers and maintenance personnel, are critical to maintaining transformers with acceptable levels of moisture, based on industry standards.



Bottom valve from a small distribution transformer. Note height off the bottom.

Transformer oil dielectric strength testing

