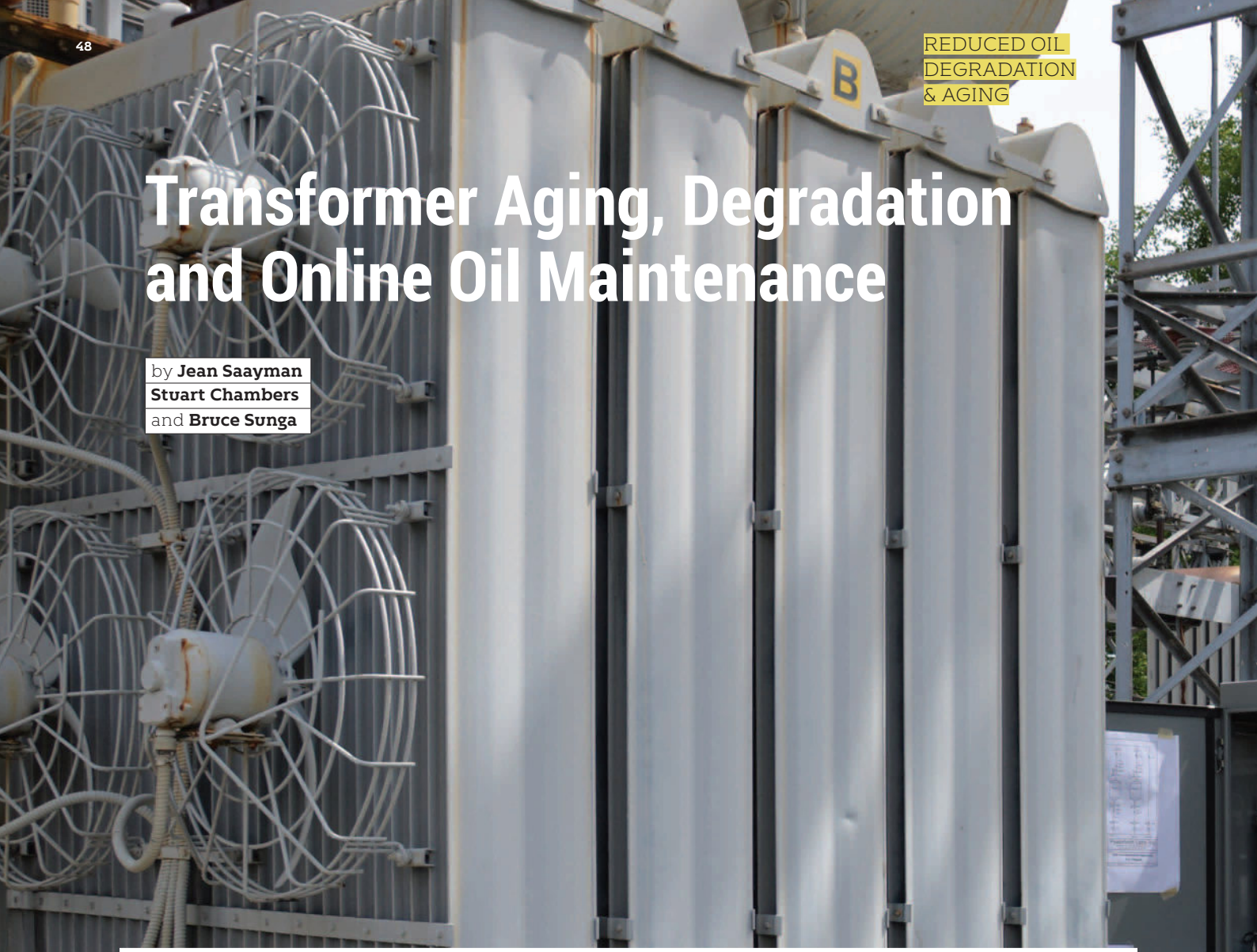
Transformer Aging, Degradation and Online Oil Maintenance

by **Jean Saayman**
Stuart Chambers
and **Bruce Sunga**



During a transformer's service life, numerous electrical phenomena and other stresses can occur that degrade the physical and dielectric properties of its oil and paper. The degradation processes are primarily chemical in nature and are accelerated by the presence of promoters, such as acids, oxygen, water, and other contaminants. If the degradation processes are left unchecked, it will eventually compromise the integrity of the equipment. Electric utilities should continually monitor and reduce the level of contaminants and oil degradation products in transformers in order to maintain the equipment's performance, prevent failure, and prolong the equipment life. Studies show that by removing these promoters from the oil, the life of a transformer can be significantly extended.

Dr. **Jean Saayman** is a Process Engineer in Powertech's R&D, Investigation & Consulting department, where he is responsible for continued research in online decontamination and reconditioning of insulating oils. His areas of expertise include transfer processes, experimental design, transformer diagnostics, and insulation degradation and aging. He also manages Powertech projects for implementing online oil reconditioning services and conducts failure investigations of electrical utility assets.

Dr. **Bruce Sunga** is the Director of the Substations Technology and Testing sector at Powertech Labs. He brings more than 25 years of commercial, industrial and electric utility experience in areas of stations and system planning, analytical studies, asset management, project management, design, automation, R&D, construction, testing, commissioning and acceptance, failure investigation and maintenance. The Substations Technology and Testing sector is comprised of two world-renowned labs, a prestigious R&D and investigations group, a substations studies group, and field testing services and asset management group.

Dr. **Stuart Chambers** is the manager of R&D, Investigation & Consulting, as well as a lead for the polymer and materials investigation facility in Powertech's Substations Technology & Testing group. His areas of research and development include transformer diagnostics, insulating paper degradation, aging properties of insulating oils, and polychlorinated biphenyls (PCB) decontamination. He has completed substantial research into insulating solids, fluids and gases for the Electric Power Research Institute (EPRI), Canadian Electrical Association (CEATI), BC Hydro and other research organizations.

Photo: Powertech Labs

The benefits of maintaining low moisture concentrations are established knowledge in the electrical industry; however, as a greater understanding of the degradation process has been gained via research and development, the benefits of removing the other contaminants has come to light. Powertech Labs has conducted several laboratory investigations into the formation of these byproducts and the benefits of removing them, and has successfully developed, studied, and implemented novel online purification techniques on operational field transformers. This article provides an overview of the aging process of transformers, the chemistry involved, and which compounds and byproducts further promote aging.

Transformer Aging

There are five prominent contaminants present in transformer insulating oils:

- Moisture
- Acids
- Polar Compounds
- Corrosive Sulfur
- Dissolved Gases

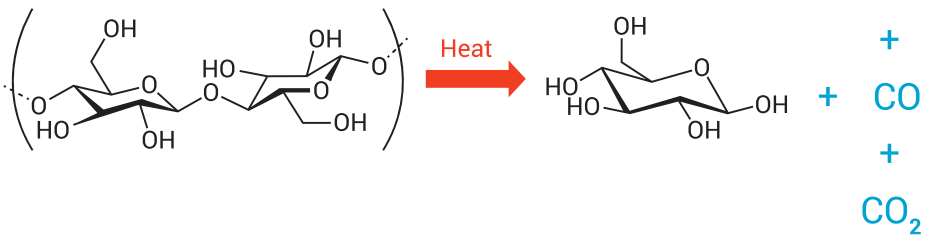
The focus of this article will be on moisture, acids, polar compounds, and corrosive sulfur and the formation of sludge. Dissolved gases can also promote the aging process, however the benefit of gases as a fault tracking method can outweigh this effect. Elevated levels of dissolved gases also present other operational issues unrelated to transformer aging and, for these reasons, there are limits at which the benefits do not outweigh the drawbacks.

The degradation processes are primarily chemical in nature and are accelerated by the presence of promoters, such as acids, oxygen, water, and other contaminants.

Moisture

Furan, moisture and dissolved CO and CO_2 are the main byproducts of cellulose (paper) degradation (Figure 1). Cellulose based degradation typically occurs due to overheating of the paper, which ranges from low energy items such as hotspots to high energy events such as arcing. The resulting decomposition compounds, gases and water from degrading cellulose dissolve into the oil as they are being formed. Oil has a saturation capacity for water and acts as a carrier of the water to the paper where it gets re-absorbed into the paper. This absorbed water "attacks" the cellulose and thus promotes further degradation which in turn produces more water and other contaminants. The process creates a positive feedback effect and can results in a rapid deterioration of the paper's Degree of Polymerization (DP). It is for this reason that the moisture content has been identified as a critical parameter to maintain assets. L.E. Lundgaard et al [1] correlated the life expectancy of a transformer to the Water Content of the Paper (WCP). Figure 2 illustrates the logarithmic nature of this effect.

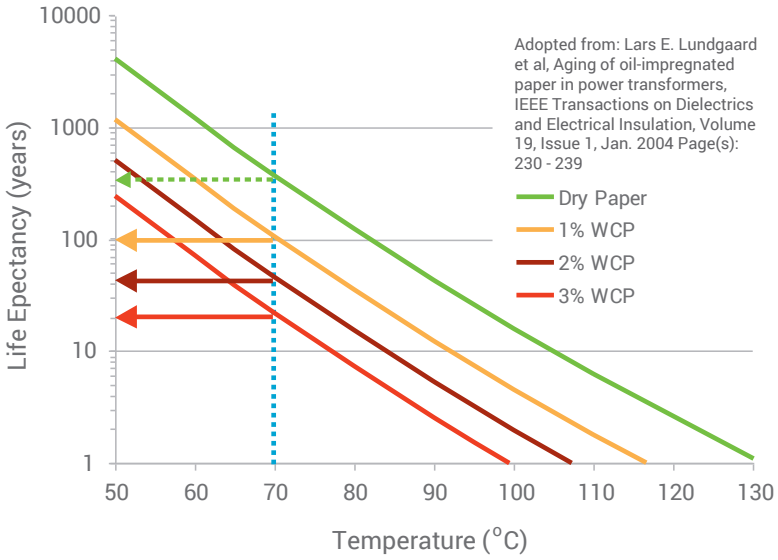
Figure 1. Furan, moisture and dissolved CO and CO_2 are the main byproducts of cellulose (paper) degradation



Not only do these contaminants deteriorate oil quality and promote further aging of the paper, they are also precursors to sludge.

Photo: Powertech Labs

Figure 2. Correlation of the life expectancy of a transformer to the Water Content of the Paper (WCP)

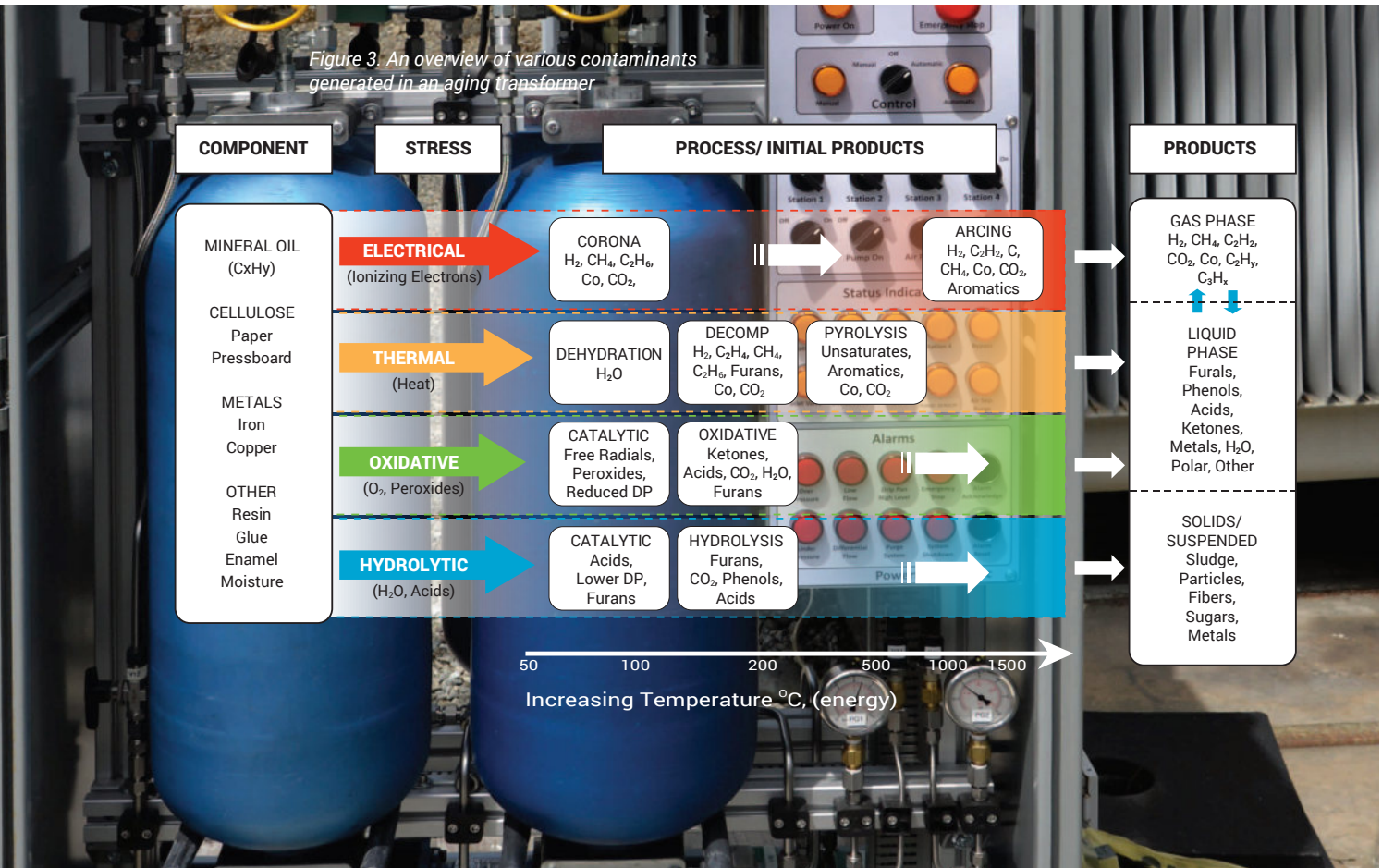


Acids, Polar Compounds and Sludge

Although moisture is a significant problem and well understood, there are other contaminants that are generated in an aging transformer with affects as detrimental, or worse, than moisture. These other contaminants that are generated from paper and oil include; acids, acetone, methanol, polar compounds, and other oxidation products. Phenolic compounds, acids, and additional polar compounds can form from the laminates, spacers, glues, and wood. Like moisture, these contaminants also promote and increase the rate of aging. A simplified yet comprehensive overview of the various contaminants that can form is shown in Figure 3, which includes details on the types of stress and components that generate these contaminants.

Not only do these contaminants deteriorate oil quality and promote further aging of the paper, they are also precursors to sludge [2]. In particular, polar functional groups like peroxides, organic acids, alcohols, aldehydes, ketones, and furans are the culprits. The precursors tend to polymerize to form larger and larger molecules. Eventually the molecules cannot dissolved or suspended in the oil, and crash out as solid deposits, a.k.a. sludge. Sludge in a system can inhibit the flow of oil causing the core to overheat and, in turn, increase the rate of aging. Once sludge has formed, it is impossible to remove without shutting down the transformer, draining the oil and physically removing sludge from the internals. This is an involved, costly, and difficult process and can be avoided by simply managing the dissolved sludge precursors.

Figure 3. An overview of various contaminants generated in an aging transformer



Corrosive Sulfur

An additional contaminant that is harmful to transformers is corrosive sulfur. Certain sulfur species attack copper, creating copper sulfides which dissolve or deposit onto the paper. These deposits cause an increase in conductivity of the paper and will eventually result in a breakdown of the insulation. There are pass or fail (qualitative) oil tests, like ASTM D1275, which identify corrosiveness; however, it gives no information on the responsible sulfur species. It is for this reason that the general term of "corrosive sulfur" is used. Note: not all sulfur species are corrosive.

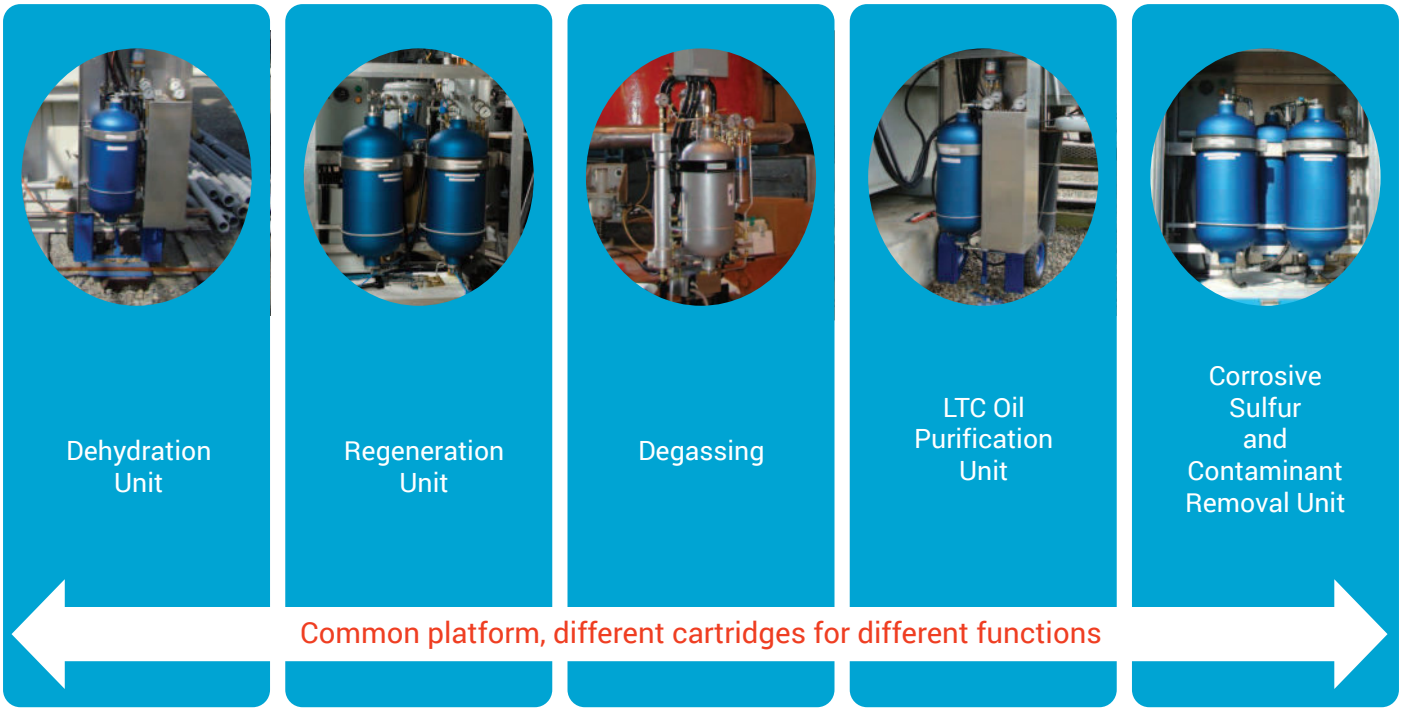
There is one specific corrosive sulfur species that was identified over a decade ago when a sudden increase in transformer failures was observed. The qualitative tests failed to identify problematic oil, and no obvious pattern to the failures could be discerned. Powertech Labs (and several other organizations) performed investigations to identify the corrosive sulfur species and ultimately discovered that Dibenzyl Disulfide (DBDS) was the common denominator in the failures. When referring to corrosive sulfur, the electrical industry typically and historically solely refers to DBDS. This contaminant had significant cost implications for utilities and Powertech Labs proceeded to developed methods to selectively remove DBDS and other corrosive sulfur species from transformer oil. Of all the contaminants which can eventually lead to the demise of a transformer, corrosive sulfur is the only one which doesn't continuously form but can go undetected in standard oil testing programs.

The traditional methodology of maintaining oil quality is to replace the oil, but new online technologies have now been developed, meaning an extended outage is not required.

Extending the Life of a Transformer

As the science behind some of the aging processes has become apparent, methods to slow the process and extend the life of a transformer have become clearer. In practical terms, one of the main methods to slowing the aging of a transformer is to maintain the oil in a good state—

Figure 4. One platform, multiple uses



not only for the purposes of good dielectric properties, but also for the purposes of controlling the promoters. The traditional methodology of maintaining oil quality is to replace the oil, but new online technologies have now been developed, meaning an extended outage is no longer required. Most of these online technologies are comparable to the concept of dialysis—they are devices that are connected to a transformer in a loop arrangement, taking out a small flow rate of oil, processing it, and returning the clean oil to the transformer. The method by which the oil is processed is selective adsorption, which allows it to remove specific contaminants. Removing the contaminants not only reduces the promoters but it also improves and regenerates the dielectric oil quality.

The Online Maintenance Industry

Services and equipment that utilize these online oil treatment technologies to restore oil quality without requiring equipment outages are becoming more prevalent. However, the majority of suppliers offer online options only for dehydration or use a non-selective adsorbent material for removing the contaminants from the oil, requiring significant amounts of time and adsorbent. Newer offerings include online oil decontamination systems which use proprietary absorbent technologies to selectively remove other contaminants from the oil of in-service transformers. These systems selectively remove all oil and paper decomposition products (acids, polar components, furans, moisture, particulate matter, and corrosive sulfur), restoring the oil quality to near new conditions. After restoring oil properties, the units keep the oil clean and dry at all times, preventing the accumulation of moisture and degradation products from reaching harmful levels, thereby extending the life of the transformer.

Powertech has successfully demonstrated this newer technology at several BC Hydro facilities, including Kent substation, G.M. Shrum Peace Canyon, and Stave Falls Generating Stations, as well as several U.S. utilities. These field trials

Photo: Powertech Labs

By eliminating moisture, acids, and polar compounds, the life of the paper can potentially be extend by several decades. By eliminating acids and polar compounds from the oil, the production of sludge can be prevented.

demonstrated results showing that the transformer oil was cleaned to as new condition in terms of dielectric strength, acid content, power factor, color, interfacial tension (IFT), and other oil quality parameters. The advantages of this technology are:

- It can operate online with an in-service transformer, avoiding system shutdown.
- It allows for significantly lower cost than other methods.
- It can be installed in a few hours and left unattended.

Specific benefits Powertech added to their Online Oil Decontamination Unit (OODU) system are:

- Safety features which include leak detection sensors, flow disruption sensors and solenoid valves as ways to safely and automatically shut down the unit.
- Capability to selectively perform one or more functions, including removal of acids, moisture, corrosive sulfur, PCBs, or degassing of the oil.

Conclusions

Many assets were originally designed with a lifespan of a few decades in mind. With aging assets and tighter operational and capital budgets, extending the life of a transformer has been a key topic of research for many electrical utilities. Research has found that by eliminating moisture, acids, and polar compounds, the life of the paper can be extend by several decades. By eliminating acids and polar compounds the production of sludge can be prevented. All these contaminants can be controlled by maintaining the oil in a pure state, and new technologies have been developed to do this in an online and continuous way.

References

[1] "Aging of oil-impregnated paper in power transformers," *IEEE Transactions on Dielectrics and Electrical Insulation*, Volume 19, Issue 1, pp. 230-239, Jan. 2004.

[2] L. Lewand, "What is sludge," *NETA World Journal*, 2006.