



Hydrogen Monitoring of Liquid-Filled Transformers: A Key Tool to Improving Transformer Reliability

by **Traci N. Hopkins**
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Transformers are the heart of any power system. Starting at generation through transmission and down to distribution, transformers play a key role in the delivery of power to end users. From homes to offices and everywhere in between, individuals expect high quality, reliable power to be available on demand twenty-four hours per day, seven days a week, 365 days per year.

When that power supply is interrupted or becomes unreliable, it is only then that they realize the scope of their dependency on this everyday resource.

Due to this ever-increasing demand, and the innate criticality of these assets to the system, it is imperative that we monitor the health of these valuable and expensive assets at

every available point throughout their lifecycle. This includes utilizing continuous monitoring systems to help transformer owners and custodians understand early and often the health and status of the transformer's solid and liquid insulating systems. One key early detection tool that is often overlooked or misunderstood is hydrogen monitoring.



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Increased Power Demand Taking its Toll on Transformers

The demand for reliable and sustainable power continues to grow, and as demand increases, so do the stresses placed on the assets that are currently in-service. Unfortunately, these increased stresses aid in accelerating the aging of the insulating systems, thus reducing the reliable life of these critical assets.

A transformer's liquid insulating system typically contains mineral oil. Transformer mineral oil is made up of a hydrocarbon chain that can degrade when exposed to heat, oxygen, and moisture. When an abnormal event occurs inside the transformer, with enough energy, the hydrocarbon chain breaks down and produces hydrocarbon gases. These gases are generated beginning at 150°C, well above recommended "safe" operating temperatures. When transformer mineral oil breaks down, the first key gas to be produced is hydrogen (H₂).

Hydrogen begins to form around 150°C, and it is an indicator that an abnormal condition has appeared, and further investigation is needed to determine the next course of action. Figure 1, borrowed from *Transformer Maintenance – Facilities Instructions, Standards, and Techniques*, United States Department of the Interior Bureau of Reclamation, Washington DC, USA, is a visual explanation of the gases produced and the temperatures necessary for these gases to be generated.

Hydrogen gas is clearly present at all fault temperatures. As the temperature of the fault increases, so does the rate of production of hydrogen gas. Because it is the first gas to appear and the only gas to be continuously present during thermal and electrical faults, hydrogen can be thought of as an early warning or "check engine light," alerting transformer operators to a potentially significant issue inside the transformer. The issue could be the result of overheating, mechanical problems like loose connections, or potential failure. The presence of hydrogen alerts operators that something is actively generating gas inside the transformer that should be investigated and addressed.

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Photo: Shutterstock

Hydrogen Detection

In most instances, determining current transformer health involves taking an annual oil sample. This practice provides a variety of valuable information on the health and status of the transformer. For example, the condition of the paper can be determined by understanding the Degree of Polymerization (DP) values from Furan testing. It can also determine if a thermal or electrical event has occurred from the profile of gases found in the sample, help you understand the current condition of the oil and much more. However, the manual oil sampling process is not without its own challenges.

Manual Oil Sampling

Obtaining a good representative sample of transformer oil is an artful process that requires a great deal of accuracy, concentration, and repeatability. More often than not, this process can be riddled with errors from improper sampling technique to poor shipping and mishandling of the sample; both by the technician in the field and in the technician in the laboratory. Furthermore, manual oil samples only provide a snapshot of gas levels at a specific point in time and do not allow the reliability or operations manager to account for anything that may occur between manual sampling schedules.

Figure 2, borrowed from *The Transformer Maintenance Guide 3rd edition*, S.D. Myers, Tallmadge, Ohio, USA clearly illustrates the solubility of gases in transformer oil.

In this illustration, it is clear that hydrogen does not like to remain in the oil and will typically escape from the transformer unless the tank is extremely airtight. This can be an issue for capturing the complete gas profile of a transformer that is only sampled once per year. If an oil sample shows Methane, Ethane, Ethylene or Acetylene with no hydrogen, it means that the hydrogen has either escaped from the transformer or from the sample. It is imperative to understand that hydrogen is generated whenever the listed gases are generated.

Continuous Hydrogen Monitoring

When an online monitoring system is introduced to a transformer, many users think that manual sampling is no longer required. This is not true. Continuous monitoring allows transformer custodians to better understand the health of that asset on a consistent real-time basis rather than on an annual schedule. Online monitors provide more pieces to the asset health puzzle by filling in the gaps between manual samples.

The information between manual samples allows reliability professionals to make better, more informed condition-based decisions with real time data. Real-time monitors alert users to issues inside the transformer at the moment when the gas is generated. This provides users with a much better understanding of how and why

KEY TOOL TO IMPROVING TRANSFORMER RELIABILITY

the gas was generated, whether it was a through-fault, a temporary overload, a cooling failure, or even for no apparent reason. While multi-gas solutions provide the most useful data for analysis, they are complex machines that require maintenance and are often difficult and expensive to maintain. Single gas hydrogen monitoring systems are cost effective and allow reliability managers to deploy devices across many transformers. Today, low-cost solid-state hydrogen sensors require no maintenance and allow transformer owners and managers to better understand the health of their assets between annual sampling and better manage the life of these assets, decreasing the likelihood of a catastrophic failure.

Selecting a Hydrogen Monitor

Hydrogen monitoring is not a new idea; in fact, hydrogen monitors

have been in use for 40 years, and are still the most popular type of online gas monitoring used. Today, transformer reliability professionals have an overwhelming variety of DGA monitoring systems to choose from ranging in both cost and functionality. During the selection process, it is important to consider sensor life, overall lifetime cost, and data access.

Sensor life is critical. From a reliability perspective, users want a device that will provide accurate information for as long as possible without the need for calibration or replacement. On average a hydrogen sensor will last one to five years. This is because the sensing element is either consumed or reaches end of life due to chemical changes when exposed to hydrogen or other environmental factors like destructive gases, heat, or moisture.

However, Palladium Nickel sensors are not consumed in the presence of hydrogen; instead, hydrogen is able to move in and out of the Palladium Nickel lattice without consuming or changing the chemical makeup of the sensor. This freedom of the hydrogen to move in and out of lattice causes a change in the resistance of the sensor. This change is measured in nano-ohms (10^{-9} ohms). Because Palladium is a natural magnet for hydrogen, the Palladium Nickel sensor does not require carrier or reference gas, nor is an extraction required to provide a measurement of hydrogen in oil or in the transformer head space. In fact, the limiting factor for a Palladium Nickel sensor is not the sensor at all. The life is determined by the electronics that manage the administration of the sensor. Therefore, robust electronics are typically provided which allow for a 10-to-15-year life of the sensor.

Overall lifetime cost of the sensor is another critical consideration. When selecting sensors for transformer monitoring applications transformer custodians should understand additional costs that may occur after installation. These costs may include repeat calibration of the sensor to maintain accurate readings, replacement of moving or rotating parts such as pumps,



Solubility of Gases in Transformer Oil

Hydrogen ¹	H ₂	7.0% by volume
Nitrogen	N ₂	8.6% by volume
Carbon Monoxide ¹	CO	9.0% by volume
Oxygen	O ₂	16.0% by volume
Methane ¹	CH ₄	30.0% by volume
Carbon Dioxide	CO ₂	120.0% by volume
Ethane ¹	C ₂ H ₆	280.0% by volume
Ethylene ¹	C ₂ H ₄	280.0% by volume
Acetylene ¹	C ₂ H ₂	400.0% by volume

Static equilibrium at 101.325 kPa and 25°C

Figure 2 SDMYERS.COM

¹ Denotes combustible gas

and replacement of the hydrogen sensing element. For traditional DGA monitors, this can be multiple times over the life of the transformer asset. In the case of solid-state Palladium Nickel sensors, we return to the life of the electronics behind the sensor which are typically rated for a 10–15-year lifespan.

Finally, data access is important. What good is a monitoring system to your reliability program if you cannot access the data? There are many applications that require alarm relay contacts, others might require an analog output (typically 4–20mA) or a communications protocol like Modbus RTU or DNP. It is important to understand the requirements for

your organization so that data can be retrieved and analyzed for proper condition-based monitoring.

Conclusion

Reliability of assets is the expectation that an object will perform as designed without interruption. Hydrogen monitoring of our transformers from initial install to end of life with high quality, long lasting, cost effective, maintenance free sensors, ensures that end users enjoy condition-based monitoring programs instead of time-based programs. This allows the reliability professional to make educated informed decisions that will extend the life of these valuable assets.

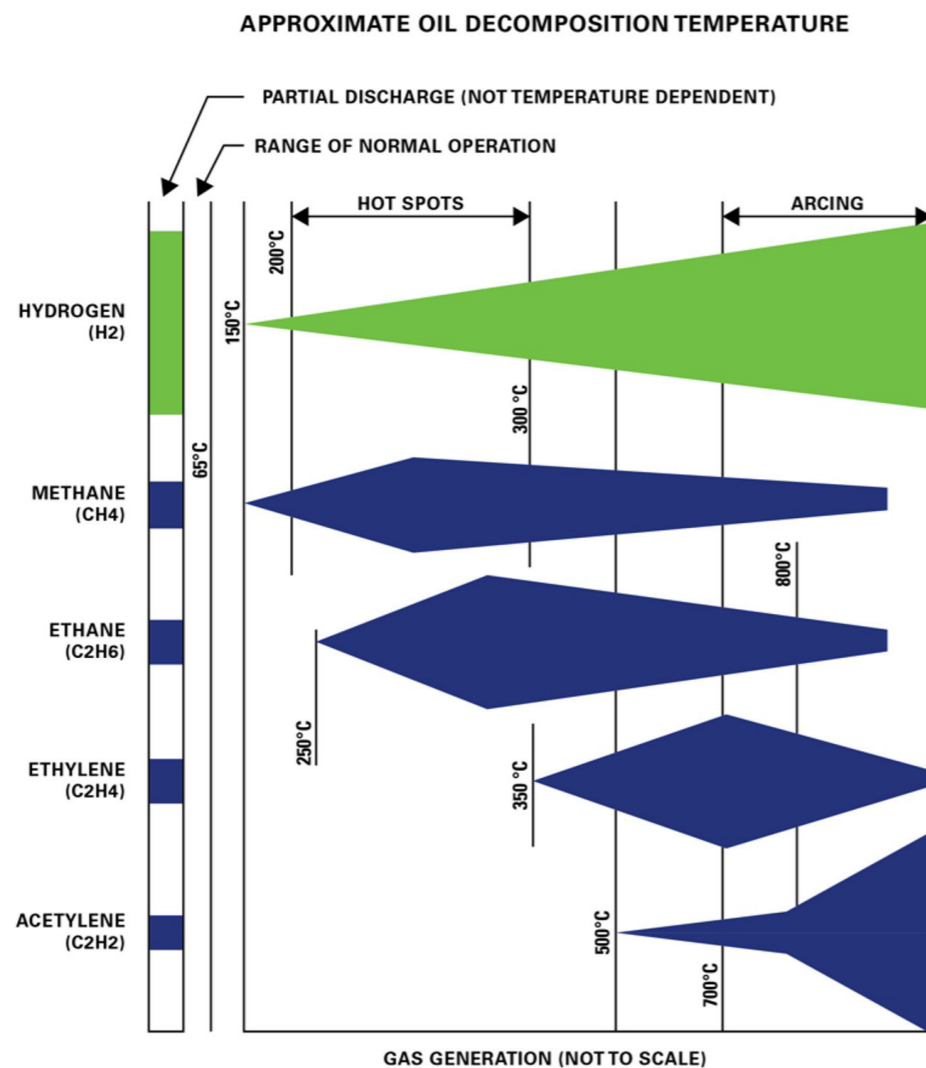


Figure 1. USBR.GOV