ARE YOU FAMILIAR WITH GAS ANALYSIS FOR THE EARLY PREVENTION OF TRANSFORMER FAILURES?

Por: Josue Rodriguez Diaz
Jose Eulalio Contreras de Leon
Elisa Zambrano

GAS GENERATION IN ALTERNATIVE DIELECTRIC FLUIDS UNDER NORMAL THERMAL CONDITIONS AND OVERHEATING

CIAP - Applied Research Center, Prolec GE
Research and Technology Innovation Park, PIIT. Apodaca, N.L.

ABSTRACT

Just as blood tests are used to detect health problems, Dissolved Gas Analysis can be very useful for the early detection of possible transformer failures.

The degradation of the insulation materials used in transformers causes combustible gases to be released inside the unit. Therefore, before a device shows signs of a problem with its operation, the levels of dissolved gases in the oil can help the user detect potential failures promptly.

To perform the Dissolved Gas Analysis (DGA), it is necessary to extract an oil sample during routine maintenance, following standard procedures to prevent altering results. Once this is done, gases are extracted from the oil sample, and a gas chromatography is performed. With this, the volume of each gas is detected in parts per million (ppm).

By doing this, we will be able to understand what is happening inside the equipment without the need of de-energizing and opening the transformer, since the distribution of gases found in the oil is an indicative of the type of electrical failures that may occur.

The 9 main gases that were found are:

- Atmospheric Gases: Nitrogen and Oxygen
- Carbon Oxides: Monoxide and Carbon Dioxide
- Hydrocarbons: Acetylene, Ethylene, Methane, Ethane
- Other: Hydrogen

The concentration of each gas is related to the temperature reached, as well as the volume of the oil at said temperature; therefore, we can say that, the level of gas concentration is closely related to the severity of the failure.

The following failures can be detected in transformers using mineral oil:

- Cellulose insulation degraded by overheating generates high levels of carbon dioxide and carbon monoxide.
- Oil overheating results in the production of hydrocarbon gases.
- Partial discharges can be detected when high levels of hydrogen are present.
- Arcing between energized parts can be detected with the presence of acetylene.
- Issues with the airtight sealing of the tank can be evidenced by the presence of nitrogen and oxygen.

Dielectric fluids for transformers are compounds formed by chemical groups with carbon-carbon and/or carbon-hydrogen bonds where the rupture of some of these bonds is the first available indicator of probable equipment malfunction that could lead to a failure if they are not detected and corrected promptly. Mineral oils are, unquestionably, the most used fluids in the electrical industry, because of their cost, availability, and properties. However, unlike these oils, natural and synthetic esters have been used as an environmentally friendly solution alternative, considering that although their chemical structure contains carbon, hydrogen, and oxygen, their diverse molecular arrangement allows the presence of different characteristics while delivering a similar performance, therefore, the generation of gases is also affected.

As the first scope, this article includes a study about gas generation under normal and overheating temperature conditions, at a laboratory level; in the same way, the gas concentration profiles shown for this type of oil, when used in power transformers during factory temperature tests, would be the first results reported in the industry.

Keywords: *gas generation, biodegradable dielectric fluids, overheating, temperature tests.*

INTRODUCTION

Dissolved Gas Analysis (DGA) is a tool used by the energy industry for monitoring and diagnosing a transformer in a non-invasive manner, with highly satisfactory results, which, when used in conjunction with alternative diagnostic methods, becomes the fastest and cheapest option to detect a possible failure in a transformer.

Since oils are made of molecules containing carbon, hydrogen, and some of them, oxygen, the breakage of C-H and/or C-C bonds may result from some electrical and/or thermal failures with the formation of unstable (radical) fragments that recombine quickly and that, through more complex reactions, form gaseous molecules such as hydrogen, methane, ethane, ethylene or acetylene. Some of the possible mechanisms for the formation of these gases are arcing, partial discharges, low-energy discharges, severe overheating of the oil and/or the insulating system [1].

These conditions occur during a single event or simultaneous events, and may result from the decomposition of insulating materials and the formation of numerous combustible and non-combustible gases; Normal operation also results in gas generation, in fact, some transformers operate during their shelf life with the presence of a substantial amount of combustible gases.

Overheating problems are one of the most common failures in the operation of oil-immersed transformers.

An overheating failure can be detected by the presence of hydrogen with methane, ethane and ethylene gases. The key gas for this type of failure is ethylene gas. The guide to interpret these dissolved hydrocarbon gases is found in Standards IEC-60599 [1] and IEEE-C57.104 [2], and has been determined based on conventional dielectric oil for transformers (mineral oil). However, the information available for other dielectric oils is scarce, and, in some particular situations, even null, especially under conditions where the transformer operates normally and it is necessary to know the satisfactory levels of operation.

On the other hand, the DGA is not only used while the transformer is in service, but also as a tool to ensure the reliability of the equipment during the factory temperature rise test. National and International Standards require this to be a routine test or prototype for power transformers, and it is included in the User Test Specifications [3, 4, 5]. By completing a DGA during the temperature test we will be able to detect hot spots in the coils, in the core, or in the mechanical tightening structures of the core and coil; hot spots that otherwise might not be detected by measurements of average oil temperature with thermocouples, and by an indirect measurement of average winding temperature by means of changes in resistance.

Nevertheless, even though the gases produced during the temperature test may be an indication of a possible problem, keep in mind that expecting zero generation of gases is not viable, since the normal heating of materials in a functioning transformer results in a given concentration of gases in the oil. However, there is little information on acceptance limits for transformers during the test using mineral oil as an insulating fluid.

This article includes information regarding the generation of gases under normal conditions and with the overheating of conventional dielectric oil and ester base oil, as well as the acceptable operating ranges of power equipment using alternative dielectric oils.

EXPERIMENTAL DEVELOPMENT

Oil characterization is essential to identify any defect when used in electrical equipment.

This process is divided into three parts, where gas generation is tested at average operating temperatures of a transformer, at overheating temperatures, in addition to the gas generation results during power transformer temperature tests using alternative fluids, as shown in Table 1. A description of the experimentation of each of these parts is detailed below.

Tabla 1.
Oils Used with Experiments

NAME	TYPE OF OIL
Fluid A	Mineral
Fluid B	Natural Ester
Fluid C	Synthetic Ester

a) Heating Vials

Initially, laboratory tests were carried out using vials with the oils being analyzed. The vials used were 20 ml, with polymeric butyl/PTFE caps. Samples of 10mL of oil were injected into the vials, which were previously purged with argon at 20.7 kPa. The oils used in the tests were degassed and dehumidified under similar conditions while a transformer is filled with each type of dielectric fluid being evaluated. The vials were placed in an electric oven to start heat treatments at temperatures of 25°, 80°, 100° and 120° C, for 24 hrs. Once each treatment was completed, the vials were analyzed in a gas chromatograph model 6890N connected with an automatic gas extraction equipment (head-space) model G1888, both made by Agilent Technology.

b) Temperature Test

For this part of the experiment, temperature tests were carried out in factory transformers using natural and synthetic ester oils to observe their thermal performance as well as using and determining the gas generation during these tests. The transformers were tested at 100% capacity for a period of approximately 30 hours. The oil samples were analyzed on the chromatograph described above.

c) Overheating

This test involved heating the oils at 3 different temperatures: 150°, 200° and 230°C. Just as with the first experiment, the oils used here were filtered, degassed, and dehumidified in order to prevent these factors from altering results. In this test, glass syringes with special caps were used to prevent spillage (Figure 1), as well as to protect against the expansion of oil. The oil samples were analyzed in the chromatograph described above.

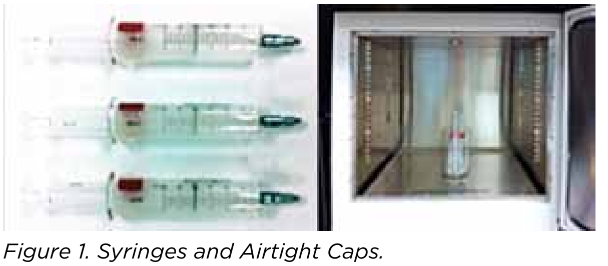

Figure 1. Syringes and Airtight Caps.

RESULTS

a) Heating Vials

The results for the heating test are shown in the following Figure.

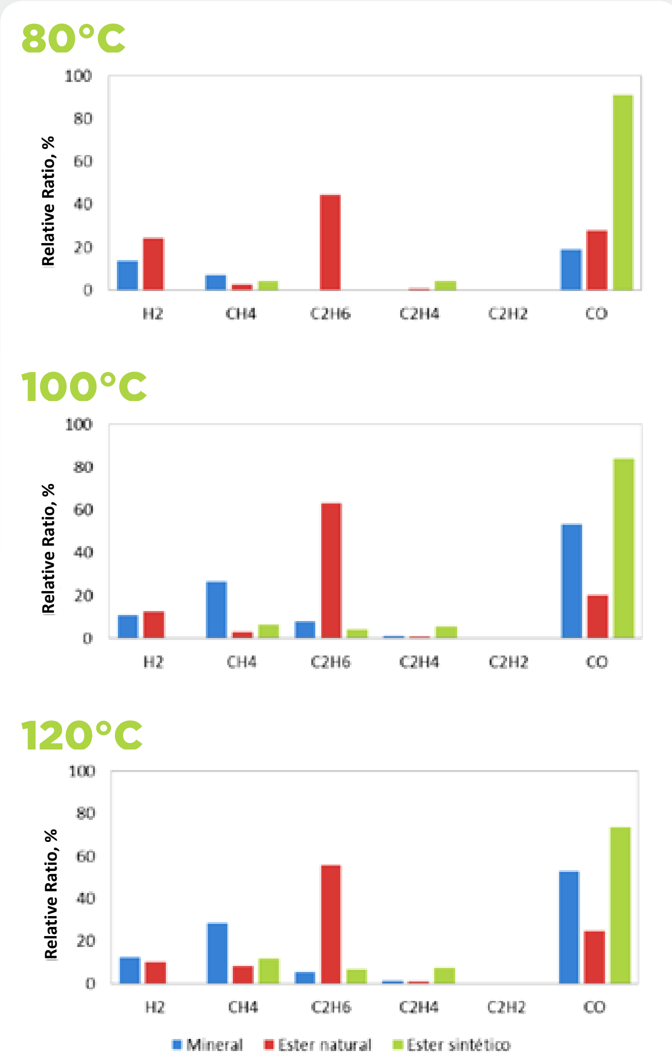

Figure 2. Gas generation in normal temperature tests.

The results show that, at low temperatures, oils generate the same type of oil, although in different concentrations and/or profiles.

Compared to mineral oil, natural ester oil had a high generation of ethane, which for a mineral oil would imply a thermal problem. For the synthetic ester oil the performance was different, however, the concentrations of carbon monoxide were higher than those in the other oils, at any of the temperatures used in this part of the experiment.

b) Temperature Test

As discussed in the previous section, standard temperature tests were performed on a group of power transformers using natural and synthetic ester oils. The relative concentrations for the equipment tested are shown in Figures 3 and 4.

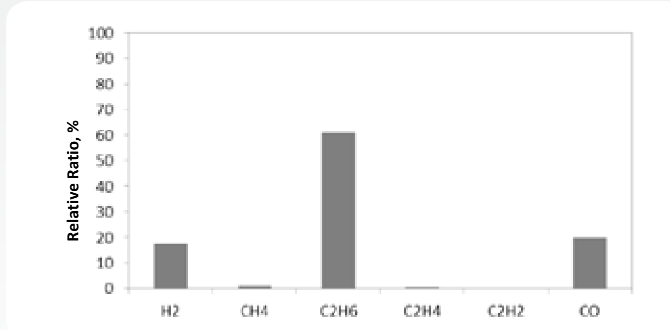

Figure 3. Relative ratio of gases dissolved in transformers with natural ester oil during normal temperature tests

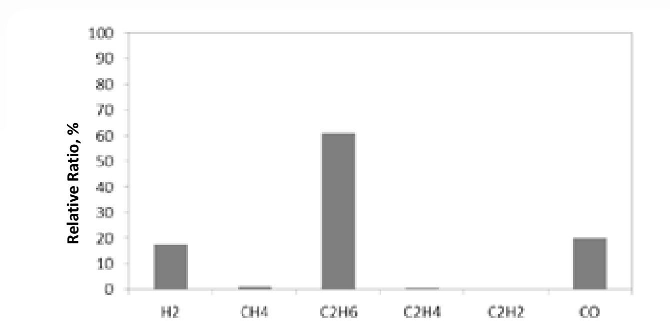

Figure 4. Relative ratio of gases dissolved in transformers with synthetic ester oil during normal temperature tests.

As we can see, in both cases of esters, the gas profile obtained in vials was very similar to the one obtained with power transformers, although it should be emphasized that different concentrations are acquired due to the amounts of oil that were used in addition to the interaction of the oils with the materials that are inside the transformer, since in the test with vials we worked exclusively with pure oil.

Figure 3 shows that the main gas generated for the natural ester was ethane, along with hydrogen and carbon monoxide, same gases that were obtained with the test in vials [6,7].

In the case of the synthetic ester, shown in Figure 4, the main gases were methane and carbon monoxide [6,7].

c) Overheating

The results for the three different oil samples that were exposed to overheating temperatures can be seen in Figure 5.

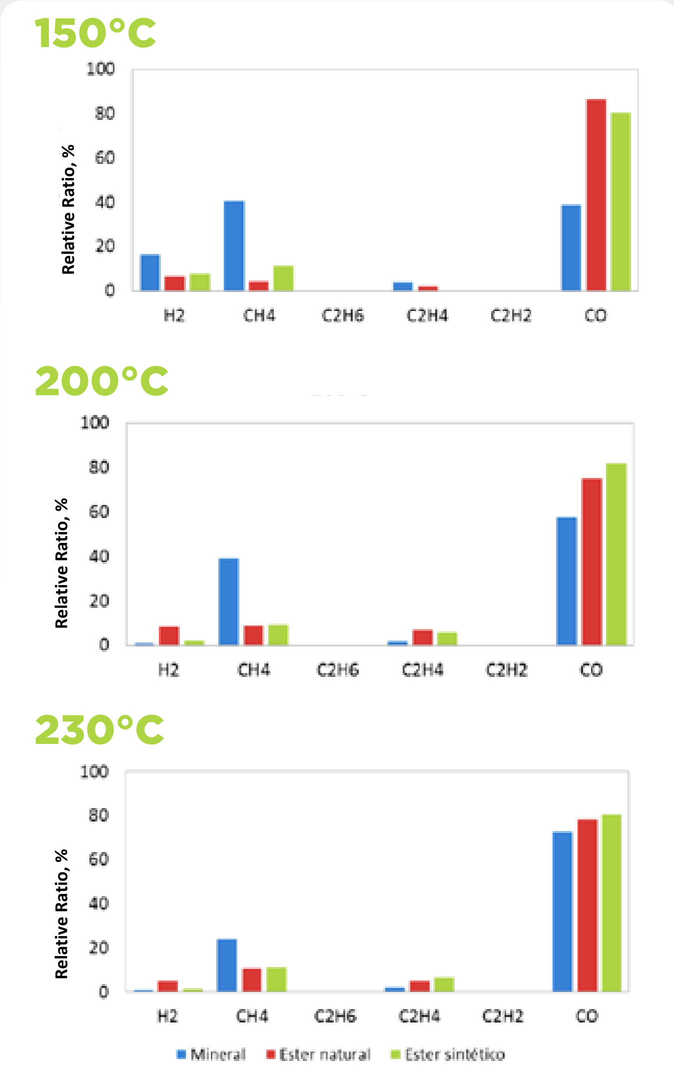

Figure 5. Gas generation during overheating tests.

Based on the results, we can see that the gases present with the three types of oil for this overheating test are hydrogen, methane, ethylene, and carbon monoxide, although in different ratios. It was confirmed that ethylene is found in greater ratio in esters, while methane in mineral oil.

CONCLUSIONS

There are two gas-generation profiles for transformers during temperature tests. Ethane gas, followed by hydrogen and carbon monoxide, will be typical for natural ester oils (soy), while carbon monoxide gas, followed by methane, will be typical for synthetic ester oils.

At least, for the temperatures used in the overheating test, no difference in gases was observed compared to the profiles obtained during laboratory tests, additional experimentation at higher temperatures is required to see significant differences.

It is important to know that low gas concentrations can be normal and that some manufacturing processes such as welding may have introduced gases into the oil. Also, the operation of some accessories such as fuses and load break switches (disconnectors), generates combustible gases under normal conditions. In addition, it is also possible that an isolated failure generates a certain amount of gases, but then it does not occur again. Therefore, a single measurement of gases is not enough to detect an issue. The analysis must evaluate the variation of the gas content over a certain period of time. This change rate will represent the severity of the problem at hand.

It is recommended to perform this test once a year, especially with transformers that provide energy for a critical operation. If high concentrations of gas are detected, it is recommended to repeat the test three or six months later, based on severity.

This method cannot identify the specific location of the failure and cannot be used if the oil in the unit has been changed. However, this is a highly valuable test for precautionary maintenance that will prevent a unit from suddenly ceasing operations at an inconvenient time.

The complete guide for a correct diagnose of the equipment based on the volume of gas present, the rate of change, and correlations among gases can be found in the standards IEC 60599 and ANSI/IEEE C57.104.

ACKNOWLEDGMENTS

We thank CONACyT for the financial support provided to carry out this research project (Innovatec Fund 2015).

Bibliographic References

[1] IEC 60599, Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis.

[2] IEEE C57.104 - 08 Guide for Interpretation of Gases Generated in Oil Immersed Transformers.

[3] Betancourt, E. and Castellanos, J., "Enhanced Field Reliability of Power Transformers by Means of a Low Gas Generation Footprint during Temperature Rise Tests-Improved Reliability Assurance Criteria". International Conference on Emerging Trends & Challenges in Transformer Technology, 2012.

[4] WG 09, "Dissolved gas analysis during heat run tests on power transformers" Electra No. 161, 1995.

[5] Guide for the Use of Dissolved Gas Analysis Applied to Factory Temperature Rise Tests for the Evaluation of Mineral Oil-Immersed Transformers and Reactors. IEEE draft PC57.130, 2006.

[6] Khan, I. et all, "Dissolved Gas Analysis of Alternative Fluids for Power Transformers". IEEE Electrical Insulation Magazine, 2007.

[7] Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester Immersed Transformers. IEEE standard C57.155, 2014.

Josue Rodriguez Diaz. *Graduated as Chemical Engineer from Universidad Autónoma de Nuevo León in 2005, and in 2009 obtained his Master's Degree in Energy Engineering Science at Tecnológico de Monterrey (ITESM). From 2008 as of today, he has worked at Prolec GE in different areas. He currently works as an Oil Specialist at Prolec GE Applied Research Center (CIAP) at the PIIT, Research and Technology Innovation Park, in Nuevo León. He is a member of the ANCE GT-14 LA Insulating Liquids group.*

Jose Eulalio Contreras de Leon. *Graduated as an Electrical Mechanical Engineer from the School of Mechanical and Electrical Engineering (FIME) of Universidad Autónoma de Nuevo León (UANL) in 2000. He obtained a Master's Degree in Materials Science in 2003 and a Doctorate in 2015, from the same institution. Since 2006, he has been a member of the Prolec GE Research and Development team. He currently works as a Research Engineer developing R&D Projects related to the application of advanced materials and new technologies for transformers. He is in charge of the Insulation Materials Laboratory at the Prolec GE Applied Research Center (CIAP) in the PIIT, Research and Technology Innovation Park, in Nuevo León.*

Elisa Zambrano. *Graduated as Electrical and Mechanical Engineer from Instituto Tecnológico y de Estudios Superiores de Monterrey in 2010. She obtained a Master's Degree in Renewable Energies from L'École Nationale d'Engénieurs de Metz in France. Then, she obtained a second Master's Degree in Electrical Engineering from Universidad Autónoma de Nuevo León. She joined Prolec GE in 2011, as an Electrical Development Engineer in the Product Development Department in the Distribution Transformers Division. Later, she worked in Technological Planning and Innovation and she currently works as Product Manager in the Division of Industrial and Renewable Transformers.*