Transformer Dissolved Gas Analysis:

Diagnostics from Factory to Operation

by **Paul Pillitteri**

Paul Pillitteri has been in the medium and large power transformer industry for 50 plus years. He has worked for three leading transformer manufactures prior to becoming a transformer consultant for the last 20 years. His experience covers most areas of power transformers including design, manufacturing, testing, repair/refurbishment, field service, and facility operations manager.

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Experience has shown that a problem or failure can go undetected at the very end of a HV dielectric test or temperature test. Large power transformer manufacturers should therefore test the quality of the oil before oil testing the transformer and perform a DGA test after HV dielectric testing or temperature run test.

Factory Diagnostics

The basic concept for dissolved gas analysis (DGA) of transformer oil has existed for at least the last 70 years. DGA was first used in the 1950s to diagnose the status of the oil/insulation system specifically after high-voltage dielectric and/or temperature run testing in the transformer factories. Experience has shown that a problem or failure can go undetected at the very end of a HV dielectric test or temperature test. Large power transformer manufacturers should test the quality of the oil before oil filling/testing the transformer and perform a DGA test after HV dielectric testing or temperature run test.

In the 1950s, and that is true even today, most end users were not aware that some large power transformer manufacturers use a DGA test to determine the final integrity of the transformer after testing. Manufacturers can or may have a table qualifying the levels of gas generation before shipment. In the early 2000s, IEEE published "PC57.130 Draft Trial-Use Guide for the Use of Dissolved Gas Analysis During Factory Temperature Rise Test for the Evaluation of Oil-Immersed Transformers and Reactors".

An example of a **table for factory guidelines after testing** might be similar to Table 1. Example of a factory table for gas generation guidelines after HV & temperature testing is given in Table 2.

A DGA sample on all new large power transformers after final factory testing is recommended to be included in customer specifications.

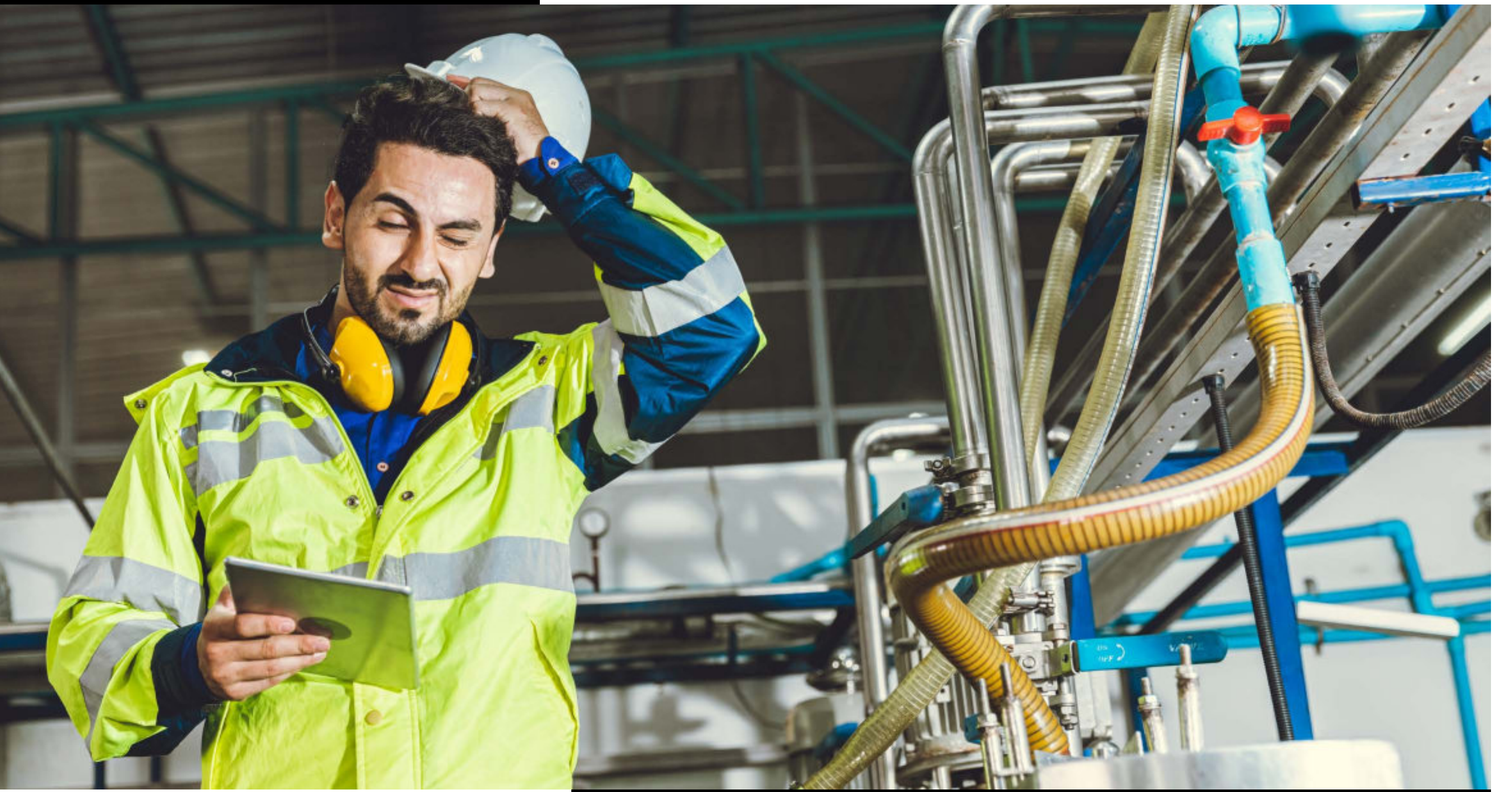
LEVEL 1	**Acceptable**
LEVEL 2	**Investigate** (requires engineering investigation)
Above LEVEL 2	**Not Acceptable** without additional diagnostics and engineering approval

Table 1. Example of a table for factory guidelines after testing

GAS COMPONENT	GAS CONTENT IN PPM	
	LEVEL 1 Acceptable	LEVEL 2 (engineering OK required)
H_2 (Hydrogen)	<11	>30
CH_4 (Methane)	<6	>25
C_2H_6 (Ethane)	<6	>25
C_2H_4 (Ethylene)	<6	>25
C_2H_2 (Acetylene)	0	0
CO (Carbon-Monoxide)	<76	>200
CO_2 (Carbon-Dioxide)	<401	>1000

Table 2. Example of a factory table for gas generation guidelines after HV & temperature testing

The DGA inquiries of almost all clients result in wanting answers to these two questions: Why is my transformer gassing? And what should we do about it?



Operational Diagnostics

As a technical support manager for a large power transformer manufacturer and a consultant for approximately 20 years, I have reviewed and given numerous DGA analysis reports for clients. The intent of a consultation is to **help the end users understand DGA** and determine a course of action for their transformer. In many cases I found it helpful to explain why DGA is necessary and the value of monitoring DGA. An example is as follows:

"**All liquid filled power transformers generate gases during operation.** This can occur with or without load on the transformer. It is well recognized that the gases generated are directly related to the transformer oil and the solid internal insulation materials. These materials undergo gradual or abrupt degradation (gassing) depending on whether the electrical stresses and thermal temperatures are mild or severe. With this understanding, diagnosis of transformer gassing must take into account many variables, but at a minimum, the following factors:

a) transformer type and age
b) loading (temperatures) on the transformer
c) transformer events
d) DGA, preferably a DGA history, as supplied by the end user

Ideally, this history shows not only all relevant gases being generated but also indicates their rate of acceleration."

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All liquid filled power transformers generate gases during operation, which are directly related to the transformer oil and the solid internal insulation materials. These materials undergo gradual or abrupt degradation (gassing) depending on whether the electrical stresses and thermal temperatures are mild or severe.

Many manufacturers, field service groups and commercial suppliers of online monitoring equipment provide their own recommendations for interpretation of DGA results. This includes digital software programs for interpretation of DGA results.
A good source of detailed information for the *transformer engineer* is IEEE STD C57.104 Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers [1].

As a technical support manager or transformer consultant, you are often required to provide DGA guidance to the following types of clients:

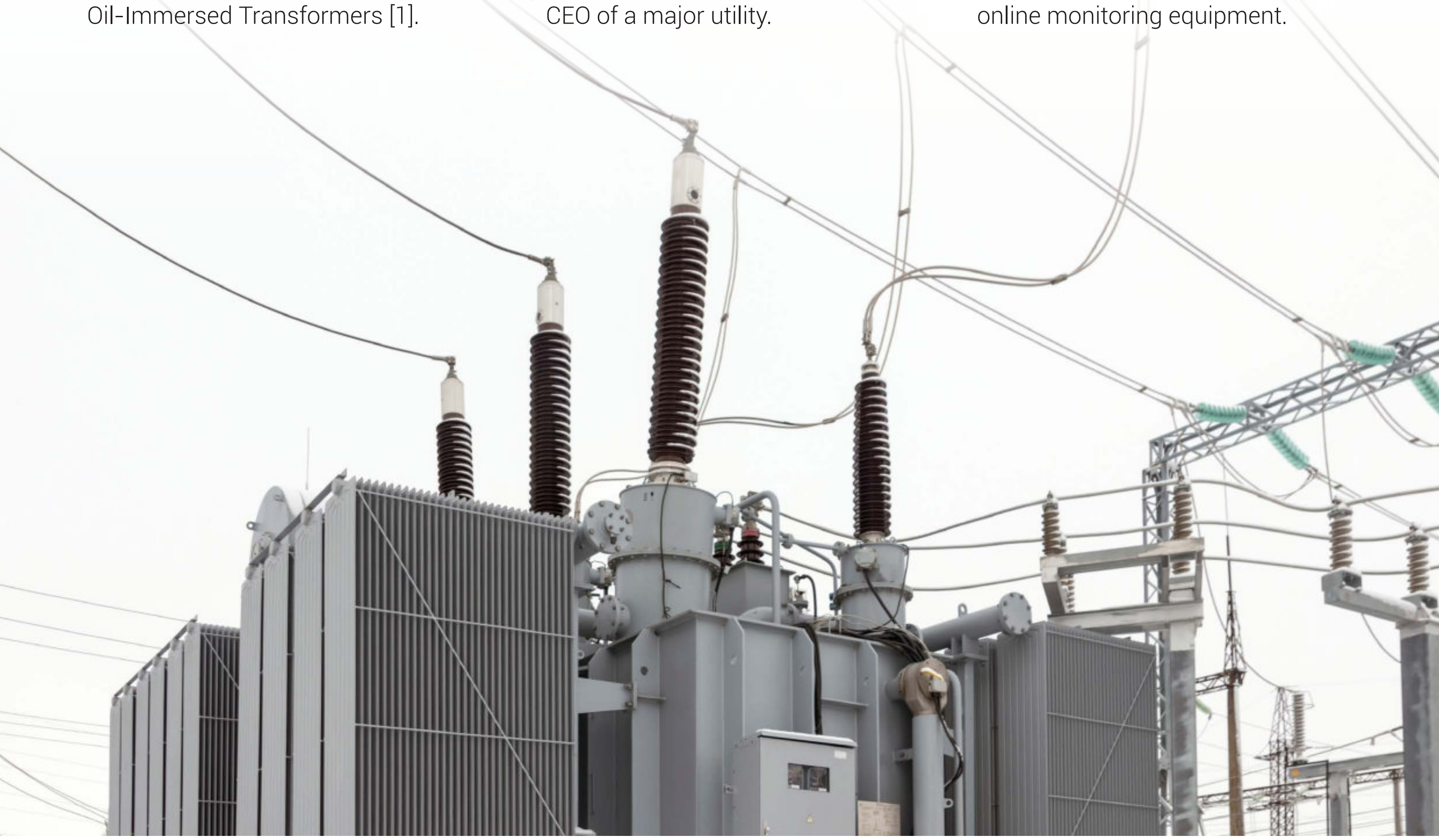
a) utility maintenance supervisors,
b) operations managers,
c) power plant managers, or even the CEO of a major utility.

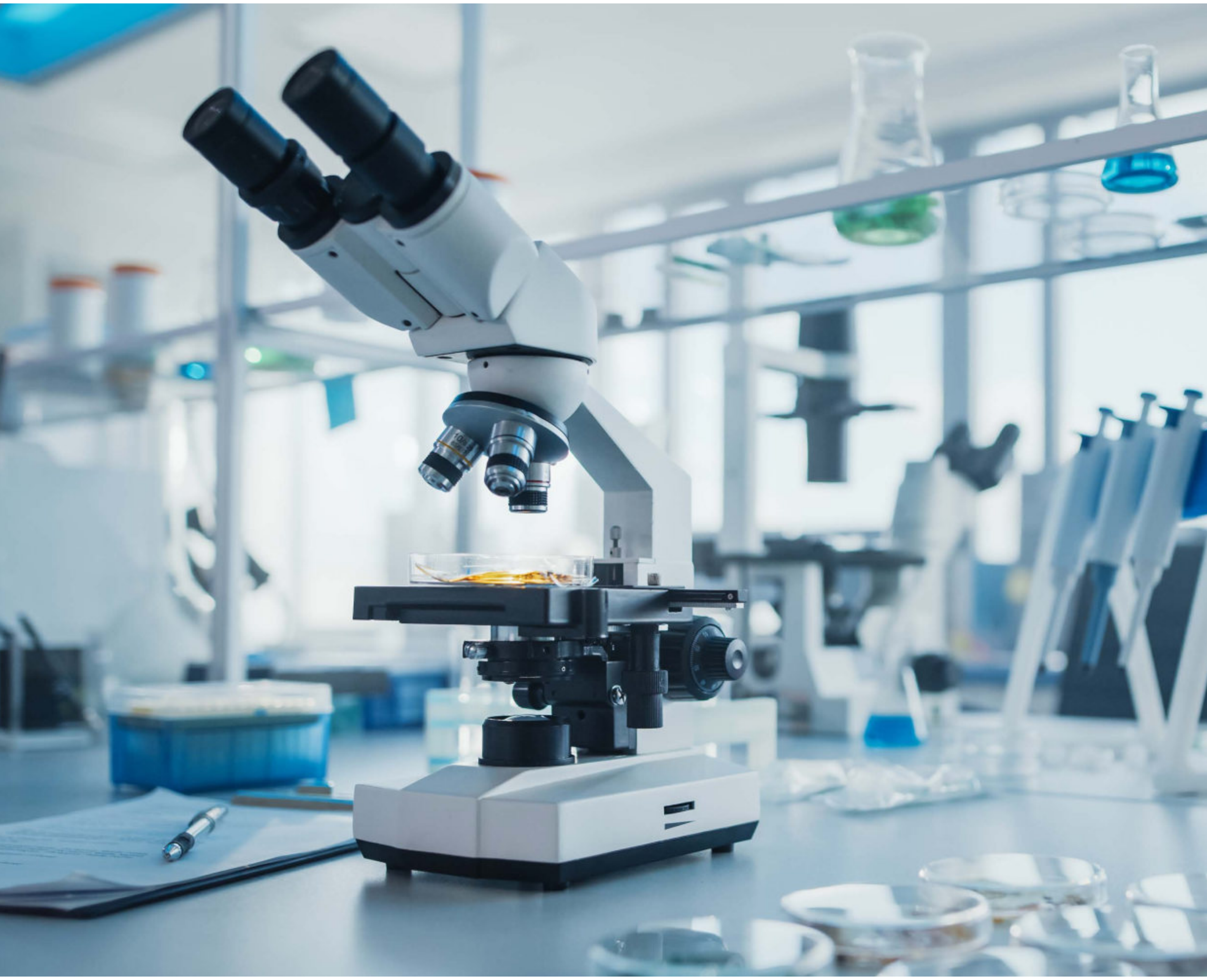
The DGA inquiries of almost all clients result in wanting answers to these two questions:

1. Why is my transformer gassing?
2. What should **we** do about it?

For all end users of large power transformers that do not have an in-house transformer engineer/expert on DGA, I would recommend the following options:

1. If possible, contact the original equipment manufacturer (OEM) for DGA guidance. This is normally done if the transformer is still in warranty. If out of warranty, most OEMs will still provide DGA guidance. OEMs will have historic design details, design changes and a history of operational knowledge that can be extremely valuable in DGA evaluation.
2. If OEM guidance is not possible, research the IEEE/PES Transformer Consultant Listing to obtain a transformer expert.
3. If online monitoring equipment provides the DGA results, contact the commercial provider of the online monitoring equipment.





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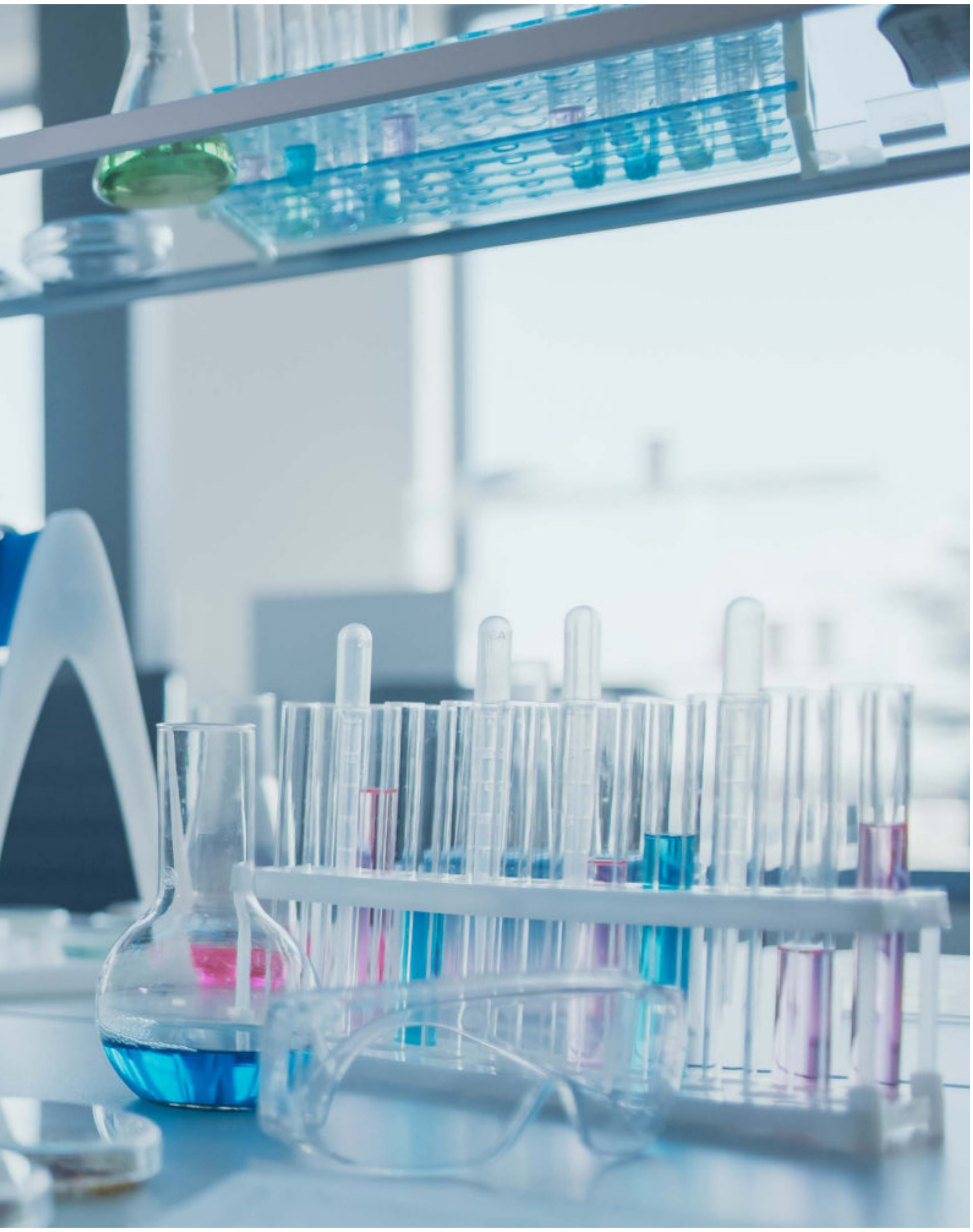
Common end users' inquiries pertaining to troubling DGA readings often occur with the transformer installation, required field maintenance, or an operational event. These inquires by end users are usually considered urgent and require an immediate response.

To conclude this article, I will outline a number of repetitive and documented cases that have occurred and continue to occur, and they are as follows:

a) **Acetylene** – An arcing or intermittent sparking condition in transformer oil can produce acetylene and hydrogen. High proportions of acetylene and hydrogen are characteristic of arcing conditions in the oil. This condition in large power transformers is extremely critical and requires immediate attention. Common repetitive occurrences:
- Transformers with centrifugal or axial flow oil pumps, rated FOA or OFAF, operate with a portion of the transformer oil circulating through the pump motor to provide cooling and lubrication for the bearings. A fault occurring in the motor winding of the pump can and will produce acetylene gas in the oil for a prolonged period of time before the pump fails to operate. This condition can be detected and corrected with a routine maintenance operation without taking the transformer offline.
- Field modifications or maintenance operations that require welding on the transformer tank walls can produce acetylene gas in the oil adjacent to the welding area.
- Field equipment used to oil fill, degas the oil, hot oil processing or add oil to a transformer may be contaminated from use on other equipment.
- Transformers with separate compartments for arc in oil load tap changers or other switching mechanisms are usually separated by a gasketed terminal board. Oil from these separate compartments may seep into the transformer tank from a defective gasket or a damaged terminal board.



- A thru-fault condition on a transformer can cause an arc (acetylene) in the transformer oil without causing the transformer to fail. It is imperative that follow-up DGAs be taken to determine if acetylene is increasing, stable or decreasing. A DGA sample is recommended on all large power transformers after a thru-fault condition.

b) **CO_2/CO Ratio** (carbon dioxide/carbon monoxide ratio) – The ratio of these gases provides a good indicator of normal or abnormal cellulose degradation. A frequent field incident that occurs all too often is the loss of power supply to the control cabinets on large power transformers. Transformers that have auxiliary cooling equipment that lose their power supply may be mildly or severely overloaded depending on the length of time before power is restored to the control cabinet. Severe/prolonged overload cases can result in a very low CO_2/CO ratio, abnormal cellulose degradation, and a very high ppm moisture content in the oil. A transformer expert should be consulted before taking any remedial actions on the transformer oil.

c) **Sulfur Hexafluoride** (SF6 gas) – SF6 gas is used primarily in gas insulated circuit breakers and switchgear. SF6 is an excellent insulator that is inert, colorless, odorless and the most potent greenhouse gas used in industry. Because of its excellent insulating properties, it is sometimes **misused** in place of nitrogen on medium and large power transformers. SF6 gas should **never** be used in oil insulated transformers for the following reasons:
1) SF6 gas is 3 to 4 times more soluble in transformer oil then either nitrogen or air. This creates a greater possibility of flashovers and arcing due to gas bubble evolution (bubbling).
2) Even with very low corona levels in transformers or load tap changer compartments small corona arcs may be present. Any sources of arcing will chemically breakdown the SF6 gas dissolved in the oil. This breakdown of the gas produces corrosive by-products, contaminating the oil and reducing its dielectric strength.

d) **Argon** (Ar) **vs Nitrogen** (N_2) – Argon is a chemically inert gas which may be used in oil filled transformers when Nitrogen gas is not readily available from a supplier. Diagnostic complications can occur if an oil sample for DGA is sent to a laboratory using gas chromatography and the laboratory is not made aware to test for Argon. Unless the laboratory is told to test for Argon, the Argon gas will show up in the total oxygen content. There are a fair number of commercial online DGA monitoring devices. I am not aware if any of them test for Argon. Argon gas is not recommended as a standard or option in oil filled transformers.

References

[1] C57.104-2019 – IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers