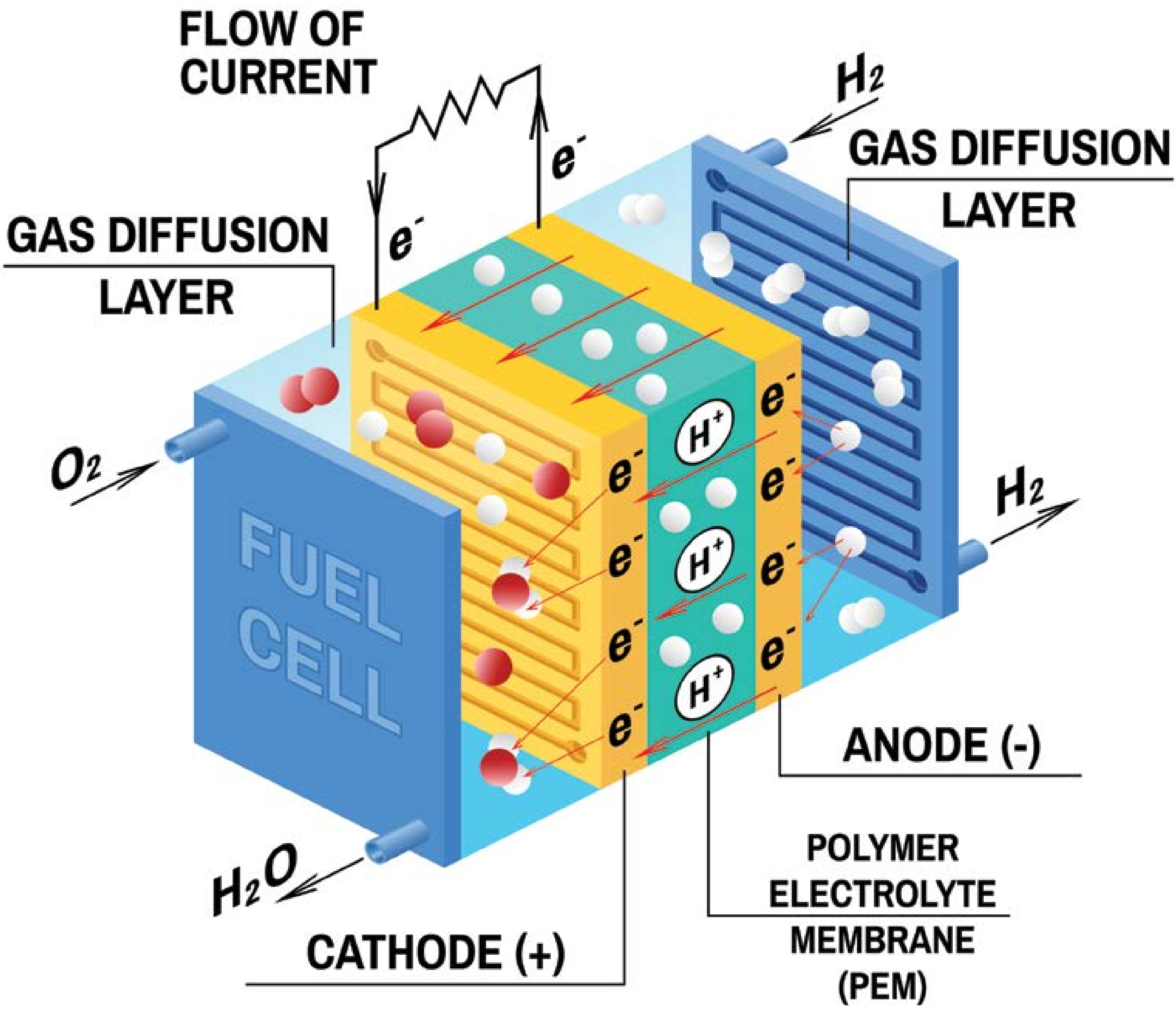

ABSTRACT

In a previous article, gas chromatography was described as the most popular method for Dissolved Gas Analysis (DGA) conducted in laboratories. In this article, we describe the established and prevalent DGA method for online and portable devices. Over the last half-century, most DGA analyses were performed by electrochemical detection. Such methods are reliable, accurate, and provide simple, low-cost, and fast responses to most malfunctions. Despite these advantages, electromechanical detection has fallen out of favor over the last two decades, giving way to new gas measurement methods. This article describes the pros and cons of electrochemical gas detection for DGA.

KEYWORDS:

Dissolved Gas Analysis (DGA), electrochemical gas detection, DGA detectors, technology, comparative comparisons

DGA is not measurement nor a mathematical or software methodology, it is rather a pure chemical method in the domain of analytical chemistry

Electrochemical gas detection for dissolved gas analysis

Introduction

Dissolved Gas Analysis (DGA) is not an electrical measurement nor a mathematical or software methodology. DGA is a pure chemical method in the domain of analytical chemistry. Analytical chemistry is a distinct science that combines chemical principles with metrology principles.

Analytical chemistry is divided into two primary categories:

- Classical methods such as titration, gravimetric, qualitative and quantitative determination, and flame tests
- Instrumental methods, considered and modern:
  - Separation science, including chromatography and spectroscopy that measures the interaction of molecules with electromagnetic radiation
  - Spectroscopy, consisting of different applications such as atomic absorption spectroscopy, atomic emission spectroscopy, fluorescence spectroscopy, infrared spectroscopy, laser, and photoacoustic spectroscopy (PAS)
  - Mass spectrometry
  - Electroanalytic techniques such as coulometric are used in water determination: for example, amperometry, which measures current versus time, and voltammetry, which measures current as a function of applied voltage

Instrumental methods and even a few classic methods are covered below.

Electrochemical DGA in oil detectors are described here.

The first real DGA online device was developed in Canada by Duval & Belanger in 1977. It consisted of a fuel cell sensitive to electron current emerging from redox classic reactions (Figure 1).

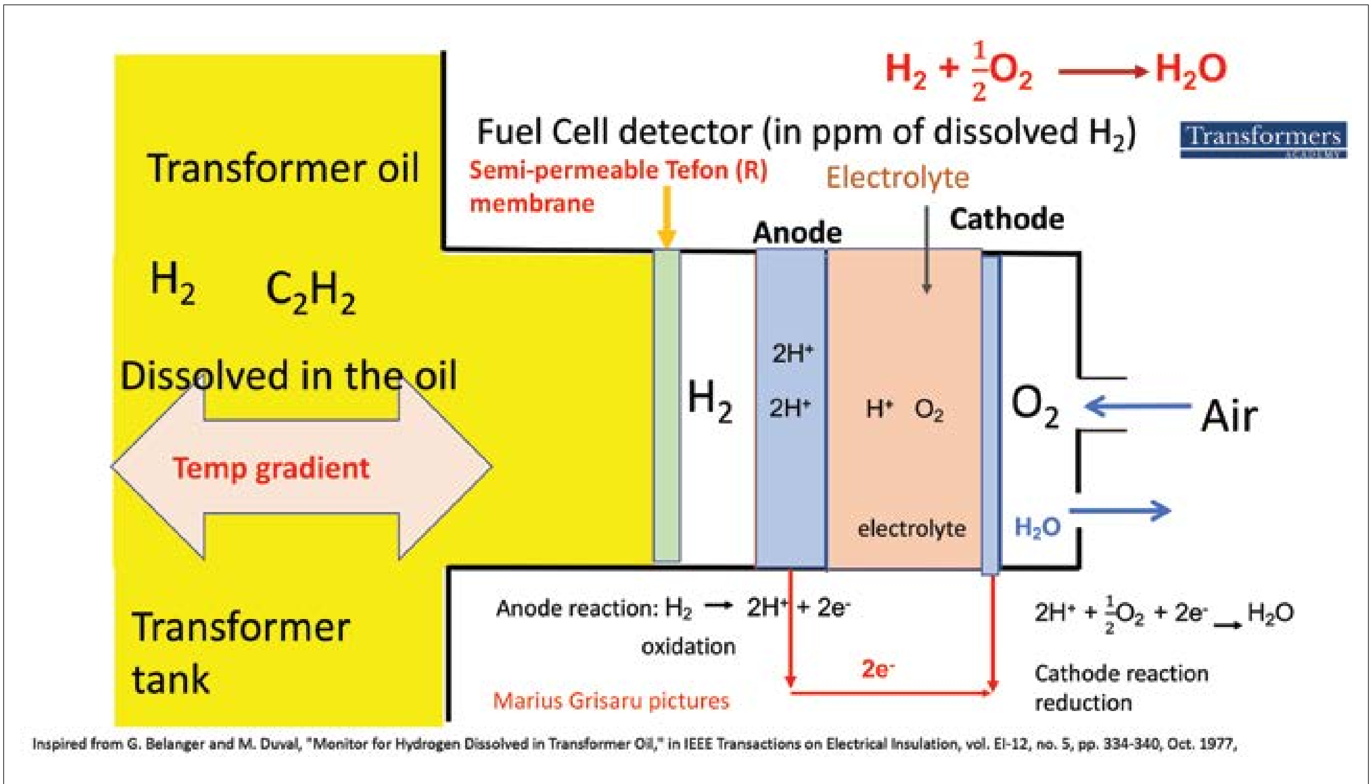

Figure 1. Principles and components for an electrochemical DGA online detector (1)

The first real DGA online device was constructed in 1977, and it consisted of a fuel cell sensitive to electron current emerging from redox classic reactions

As shown in Figure 1, hydrogen gas in oil diffuses through a thin Teflon® membrane and oxidizes electrochemically on a porous platinum electrode. This oxidation is coupled with the reduction of oxygen from ambient air on a second electrode. The current produced in these reactions is measured by the voltage drop across a sense resistor. This voltage is then amplified and displayed.

The basic device was developed commercially for online and portable Hydran devices by Syprotec, Montréal, Canada. As described in (2), carbon monoxide was added to hydrogen in the first stage and, later, ethylene and acetylene. Despite the fact that added gasses were detected at lower sensitivities than hydrogen, the device introduced the concept of measuring one single value calculated from different sensitivities of four gases according to this formula:

Early online DGA devices introduced the concept of measuring one single value calculated from different sensitivities of four gases

$$H_2 + yC_2H_2 + zC_2H_4 + xCO$$

where: x, y, and z are scaling factors.

- x: 15 ± 4 % of concentration
- y: 8 ± 2 % of concentration
- z: 1.5 ± 0.5 % of concentration

HYDRAN technology is recognized by IEEE in Std. C57.104-1991 (3) as a method for monitoring incipient fault characteristics in power transformers.

With the development of discrete single and multiple DGA online devices over the last two decades, users disparaged the concept of composite gas detection because it was impossible to distinguish between monitored gases. If the value displayed by the device exceeded limits, it was impossible to observe if, for example, acetylene increased and a transformer

Figure 2. A portable, efficient, and reliable DGA device built with an electrochemical cell. Manufactured by Syprotec

Figure 3. Three DGA online electrochemical detectors

suffered a severe fault condition or, rather, CO increased, and it was not an emergency.

As described in Table 1, inspired by CIGRE TB 783, M1*, more information than M1 may cover other fault conditions than a single gas. In both cases of M1* and M1, the operator must perform a complete DGA at a lab or with an adequate portable device.

With the development of discrete single and multiple DGA online devices over the last two decades, users disparaged the concept of composite gas detection

Benefits of the electrochemical DGA technology

- The oldest and most popular technique for online and portable devices.
- User friendly. No consumables required.
- More affordable than gas chromatographic and some spectrometric methods.
- Well established maintenance periods and lifetime.
- Free maintenance and calibration for users.
- Robust and reliable technology for almost 50 years.
- Reliable method partially standardized by IEEE C57.104 (3).
- Rapid response: less than 8 minutes for 90% step response, which offers greater assurance of rapid fault detection. Faster response than the majority of multi-gas online detectors.
- Not sensitive to environmental conditions.

The electrochemical DGA technology has many benefits and some rawbacks, yet it remains the most popular choice for conservative users for online gas-in-oil detection

Table 1. Adapted from CIGRE Brochure 783, detector capability for instant diagnosis

Faults Possible to identify	Gases measured	Type of monitor	Application
Faults Diagnose	M8 (M9)	H_2 CH_4 C_2H_2 C_2H_6 C_2H_2 CO CO_2 O_2 N_2	All the failures
	M6 (M7)	H_2 CH_4 C_2H_2 C_2H_6 C_2H_2 CO	All failures except in paper
	M5	H_2 CH_4 C_2H_2 C_2H_2 CO	
	M3	CH_4 C_2H_2 C_2H_2	
Some faults detection	M2	H_2 CO	None, only D1 & D2 on their late stage, sometimes catastrophic stage
	M1	H_2	
Detections of most faults	M1*	$H_2 + yC_2H_2 + zC_2H_4 + x\,CO$	Most of critical faults

Comprehensive knowledge of analytical chemical principles is invaluable when developing DGA devices and analysis

Drawbacks of electrochemical DGA technology

- Capable of measuring only a few DGA gases: not enough for a complete diagnosis.
- Impossible to perform normal diagnosis methods.
- Relatively high detection limits for the low range of concentration-response.
- Needs factory maintenance, between 5 and 10 years, lower than the declared maintenance periods of competitors.
- High initial investment and periodic maintenance costs relative to competitors.
- Does not provide an instant alarm in case of severe failure, as do other electrical devices such as the Buchholz relay.

Recommended diagnosis by electrochemical dissolved gas detectors

Online Hydran detectors are useful for monitoring absolute values and trends. Because it is the legacy technology on the market, enough experience has accumulated to determine specific limits.

Table 2 represents suggested limits for Hydran devices installed on power transformers. Any excursions beyond these limits require a complete DGA in the lab or with a portable device. Regardless, users must recognize that Hydran technology is incapable of determining the root cause of gas development.

Fuel cells and Hydran are not the only electrochemical approaches for DGA measurement. References (4) and (5) describe alternatives not yet commercially available.

Conclusion

Comprehensive knowledge of analytical chemical principles is invaluable when developing DGA devices and analysis. Although out of favor in recent times, electrochemical DGA detection remains the most popular choice for conservative users for online gas-in-oil detection. Yet, such devices cannot provide information about the type or cause of latent failures. Despite the abundance of online DGA technologies, users should always consider electrochemical DGA: it possesses significant advantages such as de facto standardization due to its legacy and reliability.

Like the preceding, even expensive online DGA devices that measure all DGA gases require human intervention for diagnosis and, in most emergency cases, confirmation from an offline DGA device.

Disclaimer: *This column is not a recommendation to use Hydran, electrochemical technology, or any other for online DGA measurement. Each transformer user should consider the most adequate needs for online DGA by specific needs, budget, and experts' recommendations.*

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Table 2. Suggested limits for online Hydran technology

Transformer age	Absolute value (ppm)	Trend value ppm/month)
Less than 1 year	50	20
1 – 5 years	100	10
More than 5 years	200	10

Author

Marius Grisaru holds an MSc in Electro-Analytical Chemistry from the Israel Institute of Technology. He has almost 30 years of intense experience in almost all transformer oil test chains, from planning, sampling, and diagnosis to recommendations and treatments, mainly in Israel but also in other parts of the world. He is responsible for establishing test strategies and procedures and creating acceptance criteria for insulating liquids and materials based on current standardization and field experience. In addition, he trains and educates electrical staff on insulating matrix issues from a chemical point of view. He is an active member of relevant Working Groups of IEC, CIGRE, and a former member of ASTM. He is also the author and co-author of many papers, CIGRE brochures, and presentations at prestigious international conferences on insulation oil tests, focusing on DGA, analytical chemistry of insulating oil, and advantageous maintenance policy for oil and new transformers.