# ONLINE DGA MONITORING: REVOLUTION IN TRANSFORMER CONDITION ASSESSMENT

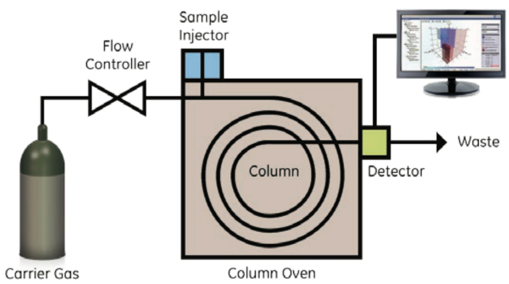
Dissolved Gases Analysis (DGA) is a well known technique used to detect possible faults inside oil filled electrical equipments mainly in-service power transformers. Still today, DGA is performed mostly by laboratories using standardised extraction methods for analysis of gases dissolved in oil. Over the past decades, there is increasing trends of on-line DGA monitoring system installed to monitor the generation of gases in transformers. This has raised a questions among potential users; which monitors should be used and how to verify the accuracy of the monitoring results.

## INTRODUCTION

Online DGA monitoring system has transformed power transformer monitoring since the 1970s. These sensors sensors are vital for assessing transformer health and initially can only detected select gases. However, an advancement in sensor technology has allows multiple gases detection for comprehensive detailed gas analysis and diagnostic. Comparing to ordinary laboratory testing where oil sampling required from in-service transformer at interval durations, online DGA monitoring has an advantages in providing realtime gases monitoring and allows asset manager to take immediate maintenance action and repairs measures. This article present several technologies used for online DGA monitoring systems, installation process and proper selection for a key success in transformer condition assessment.

## LABORATORY DGA VERSUS ONLINE DGA

Due to complexity of the equipment and process to extract and measure gases at quantities as low as one part-per-million (ppm), DGA was traditionally limited to a laboratory test. Gas extraction was normally performed using a strong vacuum pump for degassing a sample of the oil prior to analysis.




Basic diagram of a Gas Chromatography (GC) for gas extraction in oil sample

A specific gas carrier, i.e. argon is used to drive the gas sample from its injection point down the length of the column where it will be separated by Gas Chromatography (GC). This requires very tight control of gas flow rates, temperatures and carrier gas quality. Subsequently, the specific gases will be detected by two sensors, Flame Ionisation Detector (FID) and Thermal Conductivity Detector (TCD). As a result of high degree of sensitivity to environmental factors, GC requires daily recalibration for continued quality operation.

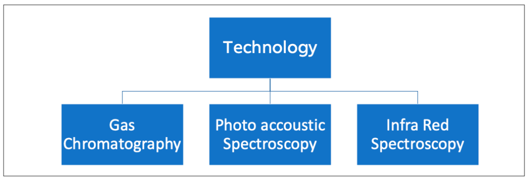
Due to the cost involved on oil sampling, logistic and laboratory testing, analysis of gases dissolved in oil would usually usually be restricted to once per year and frequent samples collected and tested only if significant fault gases were detected in the routine annual sample. As many types of faults can progress significantly in less than one year, this approach often resulted in missed diagnostic opportunities.

In recent years, there has been a dramatic increase in gas detection technology on automated and online DGA where frequency up to one sample per hour. Originally, on-line monitoring devices were based on simple versions of laboratory equipment in a way so as to allow them to work in a field environment. As these systems have evolved, a new technology has emerged to challenge the previously prevalent GC.

The first commercially successful and proven Online-DGA-Sensor for the precise and individual analysis of hydrogen (H2) and carbon monoxide (CO) came on the market in 2005. Gas extraction by this sensor was carried out by means of membrane extraction together with specific electronic gas sensors. Very soon, a multi-gases online DGA sensor was available on the market that all gases dissolved could be detected and allows diagnostic capabilities according to the internationally recognised standards became possible.

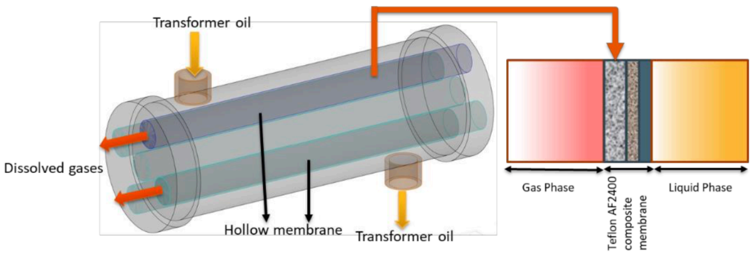
## ONLINE DGA MONITORING TECHNOLOGY

Various online DGA monitoring system has been developed and can be classified into three main technologies; Gas Chromatography (GC), Photo-Acoustic Spectroscopy (PAS) and Infrared Spectroscopy (IR).




Types of technology employed for online DGA monitors

### Gas Extraction




Headspace extraction structure diagram and membrane structure

In general, gas extraction is based on head- space or vacuum extraction principle and it is performed either by direct contact between the oil and a small gas phase above it, or through a membrane separating the two phases.

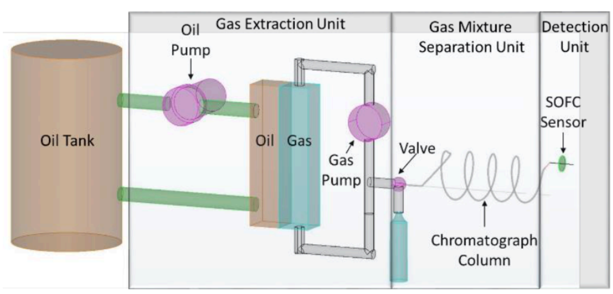
The principle of membrane extraction of dissolved gases in the oil of power transformers is today considered to be the simplest and most reliable technology and installed both for online GC and PAS detection. It applies negative pressure to the top space for the dissolved oil extraction. The membrane acts as a physical barrier only allowing gas to migrate between the gas space and liquid phase. A quality membrane offer excellent gas permeability, oleophobic characteristic and chemical and thermal stability.

## Gas Detection

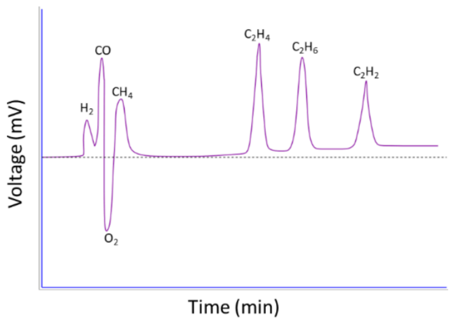
### Gas Chromatography (GC)

The most common GC detectors are Thermal Conductivity Detector (TCD) and Flame Ionization Detector (FID). These types of detectors are normally used as a combined in a laboratory environment due to their limitations. A newly online GC detector are now developed using solid oxide fuel cell (SOFC) sensor. It has high sensitivity and good repeatability to detect various combustible gases.

The dissolved gas mixture is firstly separated from oil in a gas extraction unit. Since different gases has different absorption coefficients, the gas mixture of H2, CO, CH4, C2H4, C2H6 and C2H2 is separated when passing through a chromatographic column and detected by SOFC sensor. The voltage output of SOFC detector is then sent to a data acquisition unit to be converted into digital signals representing the concentration of each gas.




Online GC system using SOFC detector

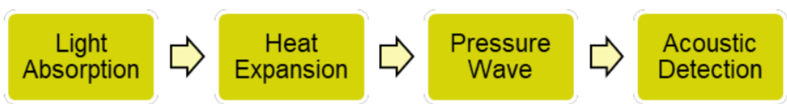



Example of voltage signal output of SOFC detector equivalent to gas concentration

### Photo-Acoustic Spectroscopy (PAS)

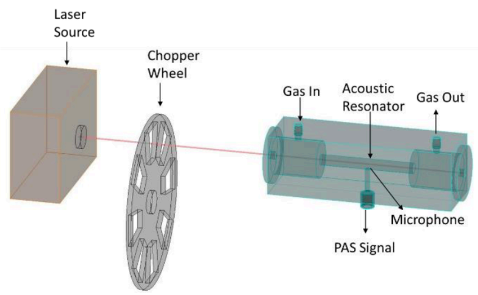
Although GC technique can accurately detect the dissolved gases, it consumes carrier gases. In addition, after extended use, GC requires calibration and replacement of chromatographic column and sensors due to the change in their properties. A photo-acoustic spectroscopy sensor uses indirect absorption spectroscopy and overcomes GC's limitation.

The principle of PAS is based on photo-acoustic effect. The dissolved gases inside an enclosure container absorb light energy and increase the gas molecules' kinetic energy, resulting in a temperature increment on the macroscopic level. This heat leads to pressure fluctuations (sound waves) and can be detected by a sensitive microphone. The concentrations of the gases are measured based on the amplitude of the photo-acoustic signal detected by the microphone.



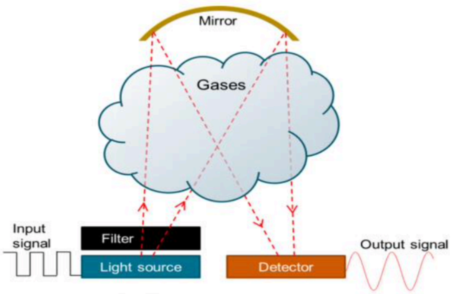

Principle of photo-acoustic effect

The light from the laser source passes through the light chopper and measured by photo-acoustic cell. The frequency of the light chopper is measured and used as reference frequency. If the frequency of the light coincides with the gas absorption band, the gas molecules will absorb part of the light. The higher the concentration of the gas in the cell, the more light will be absorbed. A photo acoustic spectrum of a sample is then recorded by measuring the sound intensity at different wavelengths, produced with a combination of a broadband IR source and a diffraction grating.




Schematic diagram of PAS detection unit

**Infrared Spectroscopy**




Schematic diagram of IR detection unit

The Infrared Spectroscopy gas sensor measure different gases by varying the radiation frequency in the infrared (IR) range. Most IR based detection either on the basis of non-dispersive infrared (NDIR) or Photo-Acoustic Spectroscopy (PAS) as mentioned earlier. The main difference in their operating principle is the actual detection of IR light absorption.

For NDIR, the intensity of IR light that passes through the gas cell is measured with and without gas absorption. The ratio of these two intensities, attenuated and unattenuated, gives the amount of absorption. This is proportional to the number of gas molecules in the gas cell, so that the IR detected light intensity decreases with the number of absorbing gas molecules. In general, all the IR techniques come in combination with either solid-state sensor, micro-electronic sensor or electrochemical cell, usually to detect H2 or O2 or H2O.

## INSTALLATION OF ONLINE GAS MONITORS

Online DGA monitoring system can be installed in the bottom oil, top oil, middle tank oil or in pipes going to or coming from radiators. Nonetheless, a general recommendation is to install the monitors as close as possible to the sampling valve. Depending on the gas formation, there is expected some delay in the monitor response.

In cases of low-to-moderate gas formation, which allow gas equilibrium to be reached throughout the tank oil, DGA results and monitor readings will be the same at all locations. In cases of fast gas formation, the main flow of hot oil containing the fault gases is drawn into the pipes going to the radiators and bottom oil, where it will be mixed and diluted in the whole tank oil. This will take time and therefore the monitor response can be expected to be delayed.

Whether connected to the top or bottom oil, some monitors are installed with long oil lines which can further delay the monitor response. The response time of a monitor will therefore depend on the monitor design, oil circulation to the monitor and oil circulation in the transformer.

## CONSIDERATION IN SELECTING ONLINE GAS MONITORS

The proper selection of online DGA monitoring system is a key success for correct assessment of in-service power transformer. Among the issues that need to pay attention by end-users are type of technology used, specification and operational parameters.

### Technology

The predominant of online DGA monitoring systems are Gas Chromatography (GC), Photo-Acoustic Spectroscopy (PAS) and Infrared Spectroscopy (IR). Different technologies has its own advantages and limitations. The various types of online gas monitors on the market for power transformers are summarised as below.

| Extraction Method | Gas measurement technology | Advantages | Limitations |
|---|---|---|---|
| Membrane, Vacuum | Gas Chromatography | Very similar to standardized techniques (IEC, ASTM)<br>Separation of signals to avoid interferences<br>Automated recalibration with on-board calibration gas | -Carrier gas (He) and calibration gas need to be replaced ~every2-4 years<br>- Depending on models, GC columns must be replaced every 3 to 5 years and there is a potential for carrier gas to leak into transformer[4]<br>-Requires management of compressed gas cylinders |
| Membrane, Vacuum, Direct headspace | Infra Red (direct absorption or photo-acoustic) | No consumable gases<br>No compressed gas cylinders | -Other sensors required to measure $H_2$, $O_2$, $N_2$<br>-Some models sensitive to contamination by oil vapours, leading to inaccuracy over time and the need for recalibration<br>- In some models, accuracy is degraded by interfering compounds present in the oil and/or the ambient air |
| Membrane, Direct contact with oil | Thermal conductivity cell | No consumable gases | -$H_2$ and CO only |
| | Electrochemical cell | | -Composite gas signal |
| | Metal-oxide sensors | | -$H_2$ and CO only, limited accuracy |
| | Metal film sensors | | -$H_2$ only |

General types of online DGA monitoring system on the market

### Specification

Some of the common parameters that can be seen in different specification of online DGA monitoring system are summarised as follow:

**Detection Range**

Detection range indicated the lower detection limit and higher detection limit in parts per million (ppm) of online DGA monitor. This should be checked regarding the intended use. For example, wind-farm transformers are well-known to generate high to very high levels of hydrogen due to stray gassing of oil and partial discharges of corona-type PD, with 90 % typical H2 levels observed close to 5,000 ppm.

**Accuracy**

Accuracy of DGA reading is critical in selecting online DGA monitoring system. The accuracy for DGA monitor must be at an acceptable level since that is what will generate the gas ppm values and which will then be used for subsequent asset management decisions. Inaccurate DGA readings may result in the wrong diagnosis, increasing maintenance and repair costs.

**Step Response**

This parameter is the most crucial one for online trending. The step response is the ability of the online DGA monitor to respond to changes in actual gas levels within a certain time duration. The slow response to fast fault may leading to transformer catastrophic failure.

**Repeatability**

The consistency in reading the same gas level is also important in selecting any online DGA monitoring system. If the repeatability value is higher, the online DGA monitor is less stable. If the monitor is less stable, accurate statistical fitting is an issue.

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***An Understanding of Power Transformer Protection***

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