This article outlines the importance of oil management and will give readers an overview of dissolved gases and their role in the transformer insulation system.

Transformer oil maintenance and management are important factors in the performance of oil-filled transformers. Many transformer owners periodically make use of companies that service their transformers and submit oil test certificates prior to and after oil purification.

Oil in transformers
Oil in transformers plays an important role in transformer reliability and life expectancy. The main functions of transformer oil are to:
• Provide dielectric strength
• Provide heat transfer for cooling
• Protect the transformer paper insulation
• Test as a diagnostic tool for condition of equipment

Oxidation is damaging to oil and is increased by the following factors:
• Heat owing to load conditions

Routine oil monitoring and diagnostic tests
Before the oil can be treated it is important to monitor and understand the dissolved gas analysis trends, oxidation and decay products,
contamination and operational problems and faults. No single test is consistently adequate for pinpointing a transformer problem, and various monitoring and diagnostic tests can be done for in-service oils, namely:

- Dissolved Gas Analysis (DGA)
- Moisture content test
- Liquid power factor / dissipation factor
- Furans
- Dissolved metals
- Oxidation inhibitor
- Corrosive sulphur

**Results analysis and fault diagnosis**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Normal</th>
<th>Elevated</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H₂)</td>
<td>&lt; 100</td>
<td>100 - 700</td>
<td>&lt; 700</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>As tested</td>
<td>As tested</td>
<td>As tested</td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>As tested</td>
<td>As tested</td>
<td>As tested</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>&lt; 12</td>
<td>120 - 400</td>
<td>&lt; 400</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>&lt; 350</td>
<td>350 - 500</td>
<td>&lt; 570</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>&lt; 2 500</td>
<td>2 500 - 4 000</td>
<td>&lt; 4 000</td>
</tr>
<tr>
<td>Ethylene (C₂H₄)</td>
<td>&lt; 15</td>
<td>15 - 100</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Ethane (C₂H₆)</td>
<td>&lt; 35</td>
<td>35 - 100</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Acetylene (C₂H₂)</td>
<td>&lt; 0</td>
<td>0 - 50</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

Table 1: IEEE guide for the interpretation of gases. (The listing in Table 1 determines the solubility of gases within oil.)

**Impurities in transformer oil**

The following tests can be used to detect impurities in transformer oil:

- Dielectric strength test – kV
- Moisture content test – ppm
- Acid content test – mg KOH/g
- Visual inspection – identification of visual impurities

**Ageing gases**

Ageing gases can be described as:

- Gases that are naturally generated by the ageing process of the active part of the transformer as a result of the transformer being constantly surrounded by various strengths of electric fields
- The constant supply of voltage stresses and current being drawn result in heat being induced into the entire transformer, which in turn results in ageing of the transformer
- More heat equals faster ageing and rapid hydro-carbon chain transformation

- The hydro-carbon gases, defined as hydro-carbon chains, generate from a thermal reaction within the oil molecules and surrounding insulating oil, with heat being the primary catalyst which, simultaneously, ages the paper resulting in thermal degradation
- Under fault conditions, the ageing gases are influenced proportionally depending on the type and severity of the fault, but only in a reactive condition
- Carbon monoxide and carbon dioxide play a critical role in determining the presence of internal winding irregularities

**Hydro-carbon gases**

- Under the normal ageing conditions of a transformer, the ppm levels of hydro-carbon gases previously mentioned are generally low and fluctuate between 0 - ± 15 - 20 ppm with special reference to Acetylene being 0 ppm = acceptable and 1 ppm = attention and manage
- If faults occur in the transformer, the type and severity of the fault can be accurately identified and addressed when hydro-carbon gases grow and interact with each other
- The rate of growth of dissolved gases is directly proportional to the rate of growth of the fault
- The type of fault can be reasonably accurately predicted with the availability of correctly tested and regularly monitored oil samples from the transformer in question

**Hydro-carbon gas interaction and fault identification**

It is important to note that insulating oil is produced to contain a primarily cooling characteristic with strong insulative and high flash point properties to assist the internal transformer solid insulation, being primarily of cellulose and fibre origin.

The insulation oil contains long hydro-carbon chains, which represent different hydro-carbon gases at various temperatures when internal fault conditions exist. The fault conditions generate various temperatures, which in turn heat the immediate oil surrounding the fault, resulting in various chemical and molecular reactions within the oil. This produces various lengths of hydro-carbon chains that are identified by means of chemical gas chromatography in order to quantify type and quantity of the various nine gases.

Defined fault - partial discharge - takes place at the existing operating temperature. The predominant gas is the hydrogen chain, H₂, which generates a volatile hydrogen gas chain - H₂ – and increases the oxygen level, which becomes electrically ionised and readily discharges. This leads to excessive corona owing to sharp edges on the designed active part, and high moisture and acid content within the oil. The higher the voltage, the higher the risk.

Defined fault – thermal degradation at low temperature – takes place at temperatures of between 150 and 300°C, with the predominant gas being the ethane chain, CH₃. The fault is indicated by a hot-spot, anywhere on the active part, with no specific reference to the location. A sharp rise in temperature heats the oil surrounding the fault, generating the ethane gas chain, CH₃.

A loose or faulty connection or conductor joint within the transformer circuit, can cause plant vibration and loading, and can aggravate the fault.
Oil samples and laboratory instruments

Oil samples should be taken by trained samplers to ensure correct sampling procedures. The sample container and the nitrile seal inside the sample tin cap play a vital role in ensuring that the sample reaches the laboratory intact for correct analyses.

The laboratory instruments required for analyses are specialised and samples are analysed by laboratory oil specialists. Regularly updated computer programs are used to do analyses according to the Rodgers Ratio and Duval Triangle methods.

The tests and analyses are also performed to applicable specifications, such as ASTM D1533, D877, D1816 and IEC 60814 ... etc.

Conclusion

The ability to interpret through analysis methodology, the oil sample and the oil sample results, and then to generate the relevant recommendations and specific scopes of work to address the diagnosis, is founded primarily on the management and formulation of the individual trend analysis of the transformer, which is based on the sample history of that specific unit.

All sample results, methods of analysis and oil sampling procedures, have to be constantly audited in order to ensure the conformity and confidence required to establish a sound foundation upon which correct and qualified oil results can be obtained. It is of paramount importance to relate a specific sample result to the transformer from which the sample was drawn and not to transformers of a similar make, design or nature of application. A sample result relates only to the sample submitted and cannot be compared to any other sample submitted or results obtained therefrom. Properly maintained and serviced oil can give practically unlimited extension of life, free from formation of sludge or excessive acidity due to oxidation.

The insulating system is the weakest link and therefore the most important part of the transformer to maintain. Of all transformer failures, 85% are attributable to failure of the insulating system. Before the oil can be treated it is necessary to monitor and understand the dissolved gas analyses trends, oxidation and decay products, contamination and operational problems and faults. No single test is consistently adequate for pinpointing a transformer problem.