POWERLINK QUEENSLAND

Oil testing and laboratory services

SAFE FOR LIFE
Everyone. Everywhere. Everyday.

About Powerlink's oil testing and laboratory services

- An industry leader
- Purpose-built laboratory
- Confidential, independent and impartial diagnosis
- Expert advice and technical support
- Emergency service available 24/7
- Comprehensive condition assessment
- Industry-approved sample containers
- Oil and insulation sampling instructions
- Training in oil and insulation sampling procedures
- Customised reports and data formats
- Customised special insulation investigations and research

With more than 35 years of experience in specialist oil, insulation and SF_6 gas testing and diagnostic services, Powerlink's Laboratory Services provides comprehensive monitoring and condition assessment for transformers, reactors, and high voltage oil and gas-filled plant.

Our purpose-built laboratory, is staffed by a team of dedicated, experienced and qualified chemists and scientists.

Powerlink's Laboratory Services team provides a comprehensive transformer, reactor and high voltage oil and gas filled plant monitoring and condition assessment service, complemented with engineering plant specialists for additional technical support when required.

The analytical tests performed by the laboratory enable you to make informed decisions on how best to maintain and operate your valuable electrical assets.

If further technical advice is required, engineering plant specialists are available to help you determine the optimum strategy.

We will partner with you to enable you to maximise the service life of your transformers, reactors and high voltage oil and gas filled plant.

We are supported by professional engineering staff who are industry recognised experts in the areas of transformer, reactor and high voltage plant design, diagnostics and asset management as well as their cumulative impacts on network performance.

We offer customers training courses in interpreting oil and insulation test data and how this can be applied to assess the maintenance, serviceability and residual life of a range of high voltage substation plant.

Working in your best interests

Independent and impartial advice

We have no ties to manufacturers or maintenance service providers meaning there is no potential conflict of interest. You can be assured of high quality advice that is independent and unbiased. Our focus is on providing clear and accurate diagnostic information and recommendations that provides you with optimum technical support for your transformers, reactors and other high voltage plant.

Polychlorinated biphenyls (PCB)

We are a NATA accredited laboratory with over 25 years' experience in PCB detection and analysis.

Comprehensive condition assessment

The condition of the internal insulation system of oil-filled high voltage plant can be assessed by performing Dissolved Gas Analysis (DGA), oil quality screens and testing for Furanic compounds.

Our extensive database of test histories for transformers, reactors and other high voltage plant ranging from 415 volts to 500,000 volts and up to 1,500MVA provides valuable reference data for analysis, diagnosis and benchmarking.

Transformer life estimation

We are a leader in developing algorithms for estimation of remnant life and failure probability by utilising DPv, Furan and DGA test data collated from several thousand transformers. With such knowledge, appropriate strategic risk management techniques can be taken.

Customised reports and data formats

Reports can be customised to your requirements and results can be supplied in any common data format. You can access detailed current and historical reports to help monitor and maintain your transformers and other high voltage plant at powerlink.com.au.

Confidentiality of your data

In conforming with our quality assurance procedures and our customer's commercial business needs, all customer test data is kept strictly confidential and is only provided to a third party if the original customer/owner of the data instructed us in writing to do so.

Round the clock emergency service

Laboratory services are available 24 hours a day, 7 days a week. Our highly trained team is always available to assist and advise in any urgent situation. Conveniently located close to Brisbane Airport, our team can pick up urgent samples directly from the airport with prior arrangement, reducing potential transport delays.

Fast turnaround

For non-urgent situations, average turnaround time for DGA and oil quality tests is 7 working days from the receipt of the oil sample. Every effort is made to ensure that a maximum of 10 working days is not exceeded.

If analysis of the oil samples is urgent, they are given priority and analysed immediately.

Sample containers

IEC approved sample containers are supplied to customers along with labels for recording sample details and sampling instructions.

Simple price structure

One price covers the supply of containers, sample testing, test data storage, maintenance and custom reporting.

Schedule of services

PLANT CONDITION ASSESSMENT

Dissolved Gas Analysis	DGA is used to monitor potential fault conditions in the oil from heating, arcing and partial discharge.
Moisture in oil	Measure of the amount of moisture in the oil to estimate the amount of water in the cellulose insulation and the risk of saturation of the oil.
Furans	Furans are used to monitor the ageing and decomposition of cellulose insulation.
Dissolved Methanol	Methanol is used to monitor the ageing and decomposition of cellulose insulation.
Degree of Polymerisation (DPv)	Measure of the average chain length of cellulose polymer using a viscosity technique. Calculate the residual paper tensile strength.
Moisture content of paper and board	Direct measurement of moisture content of paper and board. Calculation of the Gassing Tendency moisture limit of the insulation on the windings.
HV plant condition assessment insulation condition assessment	Comprehensive assessment of insulation age, condition, risk and remnant life of instrument and power transformers.
Tap changer, Circuit Breaker and Bushing condition assessment	Analysis of samples from tap changers, breakers and bushings, and assessment of condition using DGA, oil quality and particulate profiling.

OIL QUALITY ASSESSMENT

Colour and appearance	A visual evaluation of the oxidation and contamination of oil.
Acidity	Measure of the amount of acidic oxidised material in the oil.
DFF and resistivity (25C and 90C)	Measure of the amount of polar material in the oil. Responds to material not necessarily measured by acidity test.
Dielectric break down	Measure of the material which lowers the dielectric strength. Principally reacts to particles, fibres and water.
Interfacial tension	Measure of the amount of particles and polar material in the oil. Quite sensitive to trace amounts so useful to detect contamination and degradation.
Inhibitor content (DBPC)	Inhibitor is used to reduce oxidation. Important to monitor the loss of antioxidant to take steps to preserve oil quality.
Passivator content	Passivator is used to prevent unwanted reactions e.g. copper corrosion. Important to monitor the loss of passivator to preserve oil quality.
Particle and fibre - optical microscopy and SEM	Measure of the particle load in the oil. Can be used to identify particle types. For enhanced identification, characterisation by Scanning Electron Microscopy is available.
Particle count - automatic laser	Automated particle sizing system can provide a particle size profile but no identification of particle types.
Metals in oil	Measure of the amount of metallic elements dispersed in the oil.

RESEARCH, INVESTIGATION AND EVALUATION

Materials	Investigation of failures, corrosion, polymer ageing, etc.
Research and development	Powerlink provides a range of research and development services to clients.
Staff training	Training presentations are available to enable your staff to achieve a better understanding of why the tests are performed and the meaning of test results.

OIL SUITABILITY ASSESSMENT

Corrosive Sulphur (ASTM and CIGRE IEC)	A qualitative measure of the amount of reactive sulphur in the oil.
Oxidation test (IEC Method C)	Provides a relative measure of the resistance to oxidation of an insulating oil.
Density, Viscosity and Flash Point	Measure of the desired properties of the insulating liquid.
Carbon type (Brandes method)	Measure of the aromatic, aliphatic and naphthenic content.
FTIR Spectrometry	Identification of contaminants and additives.

WASTE AND ENVIRONMENTAL

Polychlorinated Biphenyl (PCB) content of oil	Measure of the amount of PCB in insulating oil.
PCB content of paper, board, cloth, soil and other porous solids	Measure of the amount of PCB present in porous materials. Useful for disposal purposes.
PCB wipe test (metal surfaces)	Measure of the amount of PCB present on non-porous materials such as laminations and tank steel. Useful for disposal purposes..
Oil in water and suspended solids	Measure of the amount of oil and suspended material in water runoff from bunds and separation tanks to determine efficiency and meet environmental regulations.

CONDUCTORS, INSULATORS, HARDWARE AND MATERIALS

Cable investigation or assessment	Assessment of failure mode and discharges for paper (eg OIP) and polymer (eg XLPE treeing) cables.
Surface contamination of disc insulators	ESDD (salt) and NSDD (insoluble soil and dirt) determination for insulator surfaces.
Surface degradation	Degradation of EPDM, Silicones and plastics (PVC, etc).
Line insulators and hardware assessments	Condition Assessment of HV line insulators (ceramic, glass, NCI) and line hardware (conductors and fittings) using materials science and HV testing (eg resistance, capacitance and voltage profiles, breakdown, withstand etc).

SF_6 CONDITION ASSESSMENT

SF_6 - quality and assessment	Measurement of air contamination and levels of fault and breakdown products of SF6 gas in GIS installations.
SF_6 in oil	Detection of quantities of SF_6 dissolved in insulating oil.

SF_6 RECOVERY AND RECYCLING

SF_6 recycling	Recovery of used SF_6 to as-new condition. Consolidation of small quantities of SF_6 into usable amounts. Analysis certificate with each cylinder. On-site treatment available.

In-house Procedures and Associated Reference Standards

Note in-house procedures are based on the reference standards but include Powerlink's equipment operating conditions, cleaning instructions, troubleshooting and health, and safety risk management.

NATA ACCREDITED TESTS

PROCEDURE	IN HOUSE PROCEDURE	STANDARD
PCB in insulating liquids	A2488172 & A2118247	ASTM D4059
PCB in paper, board and surface wipes	A2732047	ASTM D4059
Dissolved Gas Analysis	A2454491 & A2596295	ASTM D3612-02
Moisture in Oil	A2162302 & A3331087	IEC 60814
Oil Acidity	A2474242	ASTM D664 / IEC 62021-1
Furans in Oil	A2488590 & A2562701	ASTM D5837
Dielectric Breakdown	A2162306	IEC 60156 / AS1767.2.1
Dielectric Dissipation Factor and Resistivity	A2162309	IEC 60247
FTIR Spectra Analysis – Inhibitor Content	A2527035	AS 1767.2.4
Colour	A2570586	ASTM D1524
Interfacial Tension (IFT)	A2301288	ASTM D971

OTHER TESTS

PROCEDURE	IN HOUSE PROCEDURE	STANDARD
Degree of Polymerisation	A2446198 & A2446794	IEC 60450 / ASTM D4243
SF6 Quality	A2549659 & OLP071	IEC 60480
Oxidation Tests	A2526955	IEC 61125
Corrosive Sulphur	A2442603 (Silver Corrosion) A2693845	ASTM D1275 / IEC 62535 / DIN 51353 (upon request)
Particle Count	A2118475	IEC 60970
Sediment and Precipitable Sludge	A2488740	AS 1883
Chemical Identification by FTIR	A2691733	Perkin Elmer IR Library
Moisture in Paper	A2580210	IEC 60814
Passivator Testing – Irgamet 39	A2301920	BS148
Passivator Testing – Benzotriazole	A2301920	BS148
Passivator Testing – Benzyl Disulfide	OLP099	IEC 62697
Carbon type Testing	A2554308 Method 1	Brandes Method
Flash point	A2849762	ASTM 093A
Density	A2955958	ASTM D4052
Kinematic Viscosity	A2868981	ASTM 0445

Meet the team

Powerlink's team of highly qualified chemists and technicians have expertise in chemical analysis, high voltage diagnostics, instrumentation and quality control systems.

TONY TUONG NGO

Laboratory Services Manager

With over 35 years experience in laboratory operations, transformer diagnosis and asset condition monitoring, Tony leads strategic direction, quality assurance and innovation activities.

GAVIN MATTHEWS

Technical Team Leader

Gavin has more than 35 years experience in high voltage diagnostics and SF_6 testing. Specialist in condition monitoring and laboratory leadership.

VISHAL ANAND

Laboratory Team Leader

Vishal is an expert in analytical chemistry and quality systems, ensuring compliance with NATA and ISO standards.

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Dissolved gas analysis

Dissolved Gas Analysis (DGA) has become an essential tool in maintaining an efficient and reliable network, assisting companies to assess design, functional performance and condition, and determine the current value of their assets.

DGA is the process of analysing the type and quantity of low molecular weight molecules (formed by decomposition processes) that remain dissolved in insulating liquids.

DGA is part of a preventive strategy rather than being a reactive tool that assists asset management staff to plan plant maintenance, refurbishment and replacement.

The technique is applicable to oil filled plant such as power transformers and OIP Bushings, instrument transformers, reactors, circuit breakers, tap-changers and capacitors.

Methods of analysis

The most common DGA methods involve the use of Gas Chromatography (GC) to measure the key gases but apply different approaches to preparing a sample for analysis.

Sample preparation can involve 'total gas extraction', stripper column (a flowing gas extraction technique), or 'headspace' equilibrium. Each approach uses extraction efficiency factors to calculate the original composition.

Headspace analysis refers to placing a sample in contact with a gas space and allowing the volatile components in the sample to move into the gas phase before analysing the composition of the upper gas 'head' space.

Headspace analysis has been applied to DGA for many decades. Manual applications in which the sample is shaken in contact with an inert gas to establish equilibrium are still commonly used, however automated instrumentation was applied by Hydro Quebec in late 1990s and adopted by many laboratories.

Other methods include the use of infrared spectroscopy analysis in place of GC analysis, fuel cells to measure combustible gases and species selective probes.

Sample analysis can be either in the field, on line or at a remote laboratory.

It should be noted that all of the techniques mentioned will produce reliable, consistent results when an understanding of the technique and correct quality control procedures are applied.

Assessment

Abnormal releases of energy in high voltage (HV) plant, such as elevated temperatures, partial discharges and arcing, will significantly increase the production of decomposition products from the organic components of HV plant.

The pattern of decomposition products produced by this release of energy is characteristic of the material and type of energy release. For example, heating (pyrolysis) will produce hydrogen, methane, ethane and ethylene, whereas high energy releases, such as power arcing, will make large amounts of hydrogen and acetylene. From this characteristic pattern of decomposition products, it is possible to deduce the type of energy release.

Ratios of selected molecular species are typically used to remove variations and uncertainties caused by differences in oil volumes, the amount of energy released, the mass of materials involved in the fault, etc between plant items.

The relationships between gas ratios and types of energy released have been published by a variety of authors. Most notable of these are 'Roger's Ratios' and 'Duval's Triangle'.

Refinement and enhancement of Roger's Ratios by the I EC members has led to publication of IEC 60599. This is the best guide available to the 'art' of DGA assessment.

During the assessment, allowance must be made for the background production of 'fault' gases as the plant ages, the class of equipment and the behaviour and operational use / loading of each plant item. Transformers for example may have characteristic minor oil leaks between the tap changer diverter switch and main tank oil that must be considered.

Typically, 80% accuracy is claimed for assessment schemes and it is not uncommon to obtain conflicting assessments between various schemes. While assessment schemes, decision trees or computer based analysis have reduced the complexity somewhat, expertise is derived through experience.

A single set of DGA results in isolation presents little value. Results must be placed in the context of the life of the plant to gain meaningful interpretation. Therefore, a reliable history of results is required for assessment in order to establish trends in data for both a single item of plant and across families of similar items of plant. Our Laboratory Services recommend data mining to derive the most accurate and beneficial DGA results.

DGA is not limited to identifying the type of fault. The ratios of the carbon oxides formed can indicate the involvement of cellulose insulation which assists with the identification of the location of the fault. Information about the extent and rate of degradation of insulation can also be obtained.

This information can be used in conjunction with furan data to assess the condition of the cellulose insulation.

TYPICAL FAULT GAS COMBINATIONS

FAULT	H2 %	CH4 %	C2H6 %	C2H4	C2H4
High temperature	15	15	5	40	0
Corona	90	5	1	0.1	0.2
Arching	40	10	0.2	5	35

EXPERIENCE

We have over 35 years' experience in assessment and interpretation of DGA results for a range of high voltage plant.

Through an ongoing Research and Development program, the latest knowledge and technology is applied to client results. After 18 months of comparative testing and development, our laboratory was the first in Australia to provide the automated headspace technique to its clients. This allowed a substantial drop in cost to clients and a faster turnaround time.

We maintain a secure and confidential database of results to ensure a backup data source for clients as well as providing an interpretive tool. Access to results and testing progress is available via secure login on the Powerlink website in which historical and current sample results can be viewed by clients.

Furans testing

Cellulose-based insulation is extensively used in high voltage (HV) plant. The role of the insulation is to provide electrical insulation and to mechanically hold the conducting components in a specific location.

Cellulose ageing has little effect on the insulation properties until extremely advanced but substantially affects the mechanical properties of the clamping structure of the windings..

Asset managers are concerned with the ability of the solid insulation to perform its required functions across the desired life of the plant and, at any point in that life, to know the loss of functionality and the margin of risk.

One approach to testing cellulose ageing is the analysis of furanic compounds dissolved in the oil.

Furans are a family of aromatic compounds formed from four carbon atoms and one oxygen atom.

The furans that we are interested in are those formed by the decomposition of sugar molecules. Why sugar molecules? Because the solid paper-based insulation used in HV plant is primarily made of polymeric sugar molecules, the principal sugar being glucose.

When the paper degrades, some of the sugar molecules will dehydrate and reform to produce furan derivatives.

Some of the first work on the occurrence and measurement of furans in oil was performed by Burton et al in mid 1980s. Powerlink commenced furan analysis and applying furan results to plant diagnostics in 1987. Several years were spent studying the usefulness of furans to plant condition assessment and by 1993, furan analysis was considered an essential, routine test.

ANALYSIS

Furans in oil are measured by High Performance Liquid Chromatography (HPLC).

From a 10ml to 20ml sample of oil, taken as a sub-sample from routine oil sampling, the furan compounds are extracted and concentrated. This concentrated solution is injected into a HPLC where the various furanic compounds are sorted and measured.

Comparison to known amounts of furan compounds allows the concentrations in the original oil sample to be calculated.

Use of furan analysis

As plant ages, the paper-based insulation degrades and becomes brittle and less able to handle elevated electro-mechanical forces such as those during through faults on transformer windings. This is generally accompanied by a growth in prospective fault levels over the years and increasing load which increases operating temperatures and the rate of insulation ageing.

Networks that experience an elevated frequency of electrical faults due to environmental conditions accelerate the electro-mechanical ageing of the plant. These increase the risk of an unwanted event and a subsequent plant failure.

Furans are a by-product of this cellulose ageing process and increase exponentially with decreases in paper strength. By accumulating and analysing sufficient data, OTS has found that correlations can be made between furan concentrations, HV plant classes, DPv values and the effective age of the insulation.

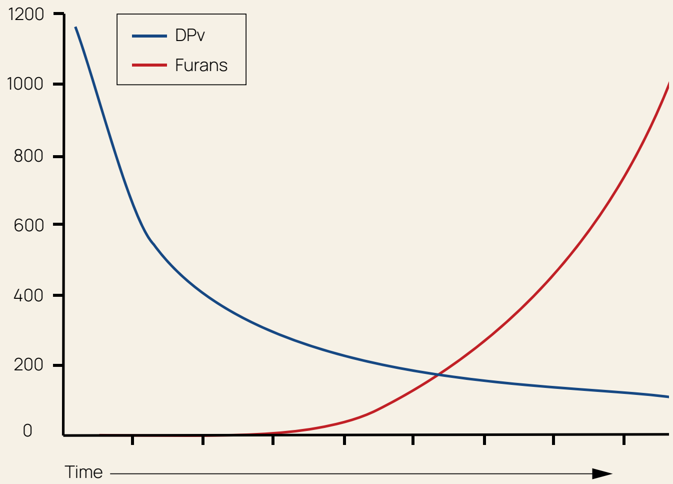
There is a relationship between the amount of furans in the sample and the DPv value of the paper insulation. As the release of furans from the paper into oil is a dynamic equilibrium (as for moisture), the information able to be extracted from measurement of furans indicates an average value of condition of the paper. This allows an average DPv to be estimated and from knowledge of the expected DPv profile in the plant, assessment can be made of the likely range of DPv values.

As transformer load fluctuates, the rate of generation of dissolved furan in the oil will also fluctuate in unison but imbedded or hidden within these fluctuations will be an obscure, increasing trend in the level of dissolved furan that correctly reflects the “real” chemical age of the cellulose insulation but with the fluctuations superimposed upon the upward trend. The art of determining the “real” cellulose insulation chemical age requires the separation of the fluctuations to reveal the “real” upward trend in dissolved furan. Corrections to the measured dissolved furan level in the oil may need to be made if the transformer internals and the oil have been subjected to vacuum treatment(s) at some stage in its life.

From a study of plant type, age and performance, it was also found that there was a correlation between plant nameplate age and furan concentrations for plant operating and performing to design specifications. It was also found that these relationships varied according to the type of plant and the type of paper used on the transformer windings (eg: thermally upgraded paper or non-TUP)..

From these studies, Powerlink was able to formulate the concept of ‘Insulation age’ (or ‘Furan age’) — the age at which normally performing plant would give the measured furan concentration.

Variation of furans and DPv with age



Comparison of this ‘Insulation age’ to the nameplate age allows asset owners to readily gauge how the plant item is travelling along its life path.

Drawing on historical fault and failure data for various plant types, Powerlink found that the risk profile for the plant could be calculated.

Application

Measurement of the furan concentrations from a single oil sample, combined with other test data and plant information, allows our Laboratory Services team to provide our clients with estimates of the expected average DPv, an effective insulation age and some concept of the risk associated with the plant.

From this knowledge, estimates can be made of the:

- life expectancy under normal operating conditions for the plant
- potential effect of harsher operating conditions
- viability of augmentation, replacement or relocation options
- value of refurbishment
- relocation risk given the mechanical strength of the cellulose
- risks are associated with abnormal operation
- current real value of the asset.

All of this is gained without plant intrusion and the associated costs and risks.

Cautions

Application of furans to plant condition assessment is not a simple task. Some difficulties with regard to interpretation and assessment stem from the general lack of theoretical knowledge about the formation of furans and the ageing processes. Other problems arise from adoption of published accelerated-ageing laboratory studies and subsequent extension and application to in-service conditions.

Moisture testing

Moisture can have a significant negative impact on the useful life of high voltage (HV) plant because it accelerates ageing of cellulose based insulation and reduces the critical insulation properties of insulation fluids. Moisture in oil tests are part of the range of comprehensive transformer monitoring and condition assessment services provided by Powerlink's Laboratory Services.

Moisture can be sourced from the atmosphere via leaks, maintenance or poorly maintained breathing systems; or the by-product of decomposition (natural ageing) of cellulose insulation.

Solid insulation acts as a seemingly unlimited supply of moisture within HV plant. Moisture is present as adsorbed water in solid insulation (>95%), dissolved water in the liquid phase (along with some associated with suspended particles) and as water vapour in the gaseous phase.

To ensure HV plant efficiency and performance, there is a need to measure and monitor the moisture content of insulating fluids.

For insulating liquids, measurement of moisture allows three parameters of the system to be monitored:

- The relative saturation of the insulating liquid can be calculated over the range of operational temperatures to gauge if the breakdown strength is lowered to a dangerous level.
- The moisture content of paper based insulation can be estimated.
- The gassing tendency of the paper based winding insulation.

For insulating gases, moisture content allows a similar estimation of relative saturation under operational conditions so as to take action to avoid possibilities of high relative saturations.

Measurement

There are several techniques available to measure moisture content. For gases, the most common is the use of dew point measurement either directly by a chilled mirror device or inferred by a moisture probe.

For liquids, a moisture probe can be used to measure the relative saturation, either by immersion of the probe in the liquid or by measurement in a gas in equilibrium with the liquid. This RH value can be converted to an equivalent ppm value if desired.

The most common method is measurement by a coulometric device which reacts iodine (generated by an electric current) with moisture of the sample (Karl Fischer (KF) reaction). The KF reaction itself is subject to a range of errors from side reactions with other components of the insulating liquid.

For coulometric devices, two common methods for introducing the sample to the reaction chamber are direct injection of the liquid sample or gas phase transfer from a heated chamber.

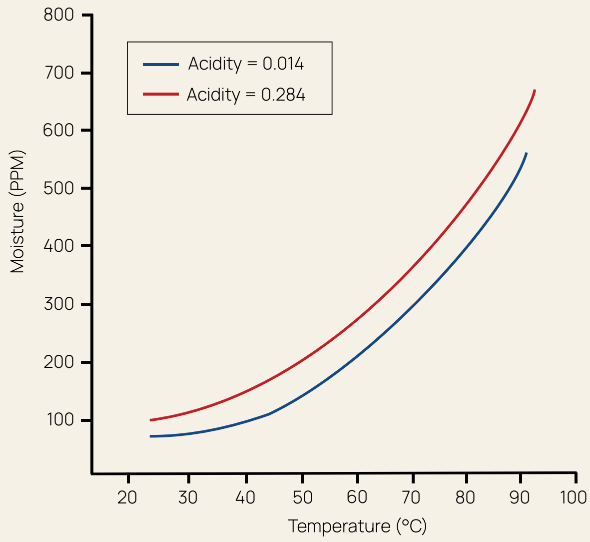
Interpretation

The RH of a liquid sample, rather than the absolute amount, has a great impact on the dielectric breakdown voltage, particularly in conjunction with fibres and particles suspended in the liquid.

Moisture dynamics in HV plant is a complicated but well studied process (the most valuable work was completed in 1950s and 1960s). Simplified, the dynamics may be expressed as: as the temperature rises, the equilibrium water vapour pressure increases for the solid insulation and water solubility increases in the insulating liquid: the trend is for movement from the solid to the liquid. The converse is true on cooling. This transfer of water across the solid/ liquid boundary is a slow process in both directions and, being predominantly a diffusion process, is temperature sensitive.

As a consequence, there are two undesirable possibilities: (I) on rapid heating of 'wet' insulation, it is possible to form high RH or free water at the winding surface, especially when hot oil at the insulation surface mixes with the bulk colder oil; and (2) on rapid cooling it is possible to form high RH or free water in the oil. Both conditions can have severe consequences.

Effect of oil ageing on saturation



How do we decide if we have 'wet' solid insulation?

There are a variety of techniques. The most accurate is to take a variety of insulation samples and directly measure the amount of water; however this can be somewhat difficult and destructive. The 'easiest' estimating technique is moisture in oil results.

One method is using the measured moisture in the oil and knowing the temperature of the windings, it is possible to estimate the water content in oil using a variety of published relationships. This technique should only be used at stable top oil temperatures above 50°C to ensure that quasi-equilibrium has been attained (too big a temp difference will still exist).

Gross errors will be introduced if operating temperatures are below 40°C due to low transfer rates. It is noted however that from a practical point of view, only the winding hot spot and top oil temperatures are visible from the outside of the transformer when oil sampling and not the average temperature of the distributed winding cellulose mass and the oil passing through them. Also, it is rare that quasi-equilibrium is normally achievable in most transformers.

How do we decide if we have 'wet' liquid insulation?

The desire is to avoid high values of RH (say above 70%). Using the operating temperature and the measured RH, it is possible to calculate the RH over the expected operating temperature range. Such routine sampling is generally not possible, however, it is possible to estimate extreme conditions from appropriate data.

Knowing the winding or top oil temperature is essential to obtaining the best assessment of moisture impacts. Oil sample temperatures should always be included on the sample information sheets which are returned to the Oil Testing Services laboratory with oil samples.

Based on experience, Powerlink uses a simple rule of thumb in cases where temperature data is not available — the maximum measured amount of water in oil should be less than 30ppm. This will avoid most dangerous levels of RH over normal operating temperatures (ambient >15°C, top oil <60°C) in Australia.

Oil quality testing

Significant demands are placed on insulating oil. It must perform as a dielectric material, a heat transfer medium, withstand high temperatures and arcing, resist oxidation and be compatible with all constructional materials. If it fails in any of these areas, the longevity and performance of high voltage (HV) plant will suffer.

To achieve these requirements, you must start with an oil of suitable talent and then maintain that oil in peak condition. To achieve reliability, routine monitoring and assessment of oil quality is essential throughout its life. The following tests, taken from the suite of tests offered by our Laboratory Services, are considered to be the most important in an oil selection, acceptance and monitoring programme.

Primary routine tests

These tests are performed on all routine samples or during problem solving.

Moisture content

The presence of excessive moisture accelerates paper degradation and lowers the dielectric strength and may increase the gassing tendency of the cellulose in the windings. Measurement of oil moisture content allows the relative saturation of the oil to be calculated as well as an estimation of the amount of moisture in solid insulation.

Acidity

Acidity (neutralisation number) is a measure of the oxidation of the oil. High acidity levels are associated with increased paper degradation, sludging, decreased dielectric strength and greater dielectric losses.

Dielectric strength

Dielectric strength is a measure of the oil's ability to withstand electric stress. Dielectric strength is a good indicator of the presence of suspended particles and fibres, especially when excess moisture is present.

DDF and resistivity

This is a measure of the amount of polar or polarisable material in the oil. Oil is quite sensitive to small amounts of these materials, so this test is useful for the detection of contaminants.

Interfacial tension (IFT)

IFT measures the surface tension between water and oil interfaces. Particles and dissolved polar materials gather at the interface and lower the surface tension.

Secondary tests

These tests are not routinely performed on all samples but may be routinely performed for specific items of plant or during problem solving.

Additives

Oxidation inhibitor and passivator concentrations will reduce during the life of the oil. To ensure adequate protection of the oil, it is necessary to monitor concentrations so as to take action when levels become too low.

Particles

Particles in the oil can be a sign of ageing of oil (sludge) and paper (fibres), wear metals, surface corrosion and coking due to abnormal heating or arcing. A range of particle identification tests is offered;

- Particle profile (size distribution) by automated or optical means,
- Particle identification by optical or electron microscopy, SEM/EDX.

Dissolved and suspended metals

Metals-in-oil analysis is used to measure metal corrosion and wear metals.

PolyChlorinated Biphenyl (PCB) content

PCB is of concern to the industry due to its classification as an intractable waste. PCB content is generally measured before disposal of plant components due to environmental concerns and before maintenance due to occupational health requirements.

Acceptance tests

These tests are generally only performed as a type test prior to accepting an oil for use or during problem solving.

Corrosive sulphur

Sulphur present in oil can be beneficial by acting as an inhibitor. However, some sulphur compounds can be detrimental due to formation of semi-conduction sulphides which lower the insulation resistance. ASTM and CIGRE tests are available.

Oxidation resistance

If oil is exposed to oxygen, then oxidation reactions can take place. The oxidation by-products will degrade the oil and paper insulation. An oxidation resistance test will provide a measure of the performance of the oil.

Carbon type

This test provides a breakdown of the composition of the oil in terms of aromatic naphthenic and paraffinic species. The more aromatic the oil becomes, the less compatible it can be with other materials and the lower the oxidative resistance.

Miscellaneous tests

Gassing Tendency, Viscosity, Density, Flash point, Fire point, Aniline point, Pour point. Physical and chemical properties of the oil.

TYPICAL FAULT GAS COMBINATIONS

	RESULT	L	M	H	DIAGNOSIS
Moisture @ 20°C (original)	1 [11]	5	8	10	OK
Acidity	0.198	0.1	0.125	0.15	Terrible
Break Down	>75	60	55	50	OK
DDF	0.0895	0.1	0.15	0.2	OK
Resistivity	2	10	3	1	Poor
IFT	25	28	24	22	Fair
DBPC		0.3	0.15	0.1	
Comment OQ	Acidity level is high. Resistivity is low. Other oil quality results are acceptable.				
Oil Condition	Monitor				

Assessment

Results of oil tests are assessed against published international standards and criteria.

Based on these assessments and our Laboratory Service's knowledge base drawn from historical results, we will evaluate the performance level of the oil and recommend an appropriate course of action.

Applicability

These tests are suitable for application to any oil-filled HV equipment including (but not restricted to) power and instrument transformers, reactors, circuit breakers, tap-changers and RMUs.

Sulphur hexafluoride (SF_6)

Sulphur hexafluoride, SF_6, is a chemically inert, non-toxic gas that is used in switchgear and other high voltage electrical equipment for electricity transmission and distribution. The gas acts as an extremely efficient insulation medium and can also assist in arc suppression during the switching process. It can achieve this due to its high dielectric strength and its ability for recombination. As a consequence of its stability, SF_6 is the strongest known greenhouse gas. For this reason, control and recording of SF_6 losses are tightly governed by Australian and global legislation. Powerlink Queensland's laboratory leads the way in testing used and reclaimed SF_6 for various contaminants that can impact on the efficient operation of electrical equipment.

SF_6 analysis

Although SF_6 is highly stable at normal operating temperatures, failures may occur due to a portion of SF_6 molecules decomposing under electrical stress.

SF_6 can be decomposed when subjected to an electrical discharge by way of an arc, spark or corona discharge. Discharges during switching operations over time, lead to increased concentrations of toxic and highly-corrosive decomposition products. The decomposition of SF_6 under electrical stress

depends on insulation gas pressure, electrode materials, and the inner surface materials of the equipment. Additionally, impurities such as O2 and H_2O play an important role. Water vapour exists everywhere and is always part of total gas pressure e.g. atmospheric and gas insulated equipment.

Initially, arcing causes the thermal dissociation of SF_6 to SF_4, $S2F_2$, $S2F_{10}$ (decomposes to SF_6), metal fluorides from electrode materials (e.g. WF6 , AlF3) and carbon based compounds from lubrication material (i.e. CF_4, COS, CO_2, CO). Both SF_4 and S_2F_2 are very reactive and react readily with O_2 and/or H_2O to form sulphur oxyfluorides SOF_4, SOF_2, SO_2F_2, SO_2 and HF.

Further reaction of SOF_2 with HF in the presence of SiO_2 based insulation material produces SiF_4. These contaminants prevent the continued safe operation of the switchgear. Hence, on-site condition monitoring of the fill gas is required, through the utilisation of field analysers and in the laboratory by various analytical methods.

The International Electrotechnical Commission (IEC) has defined the quality requirements and properties for technical grade SF_6 (IEC 60376) and the guidelines for testing and reclaiming used SF_6 from electrical equipment and the specifications for re-use (IEC 60480). The following is the maximum concentrations of contaminants in SF_6 for re-use:

- Air and/or CF_4: 3.0%
- Moisture Condensation (Dew Point): - 40.0°C
- Total gaseous decomposition products: 50 ppm v

Analysis of decomposition products in SF_6

Our laboratory measures the different contaminations in used and reclaimed SF_6 by Gas Chromatography (GC), Hygrometry (Dew Point) and Fourier transform infrared spectroscopy (FT-IR).

In GC, a gaseous sample of used or reclaimed SF_6 is carried through a heated column by hydrogen gas (Mobile Phase). The contaminants in the sample interact with the Styrene/ethyl vinylbenzene resin packed column (Stationary Phase, SP). The contaminants are separated and elute from the column at different times based on its affinity for the SP and are then identified by the detectors.

Dew Point/Frost Point ($T_{d/f}$) is defined as the temperature at which the partial water vapour pressure (p_w) of a gas is equal to the vapour saturation pressure (p_{ws}) i.e. the temperature at which water vapour condenses into dew or frost A hand held dew point meter fitted with a sensor is directly connected to an SF_6 cylinder. The SF_6 gas flows past the sensor and is measured as a function of $T_{d/f}$ °C along with the relative humidity %RH. The dewpoint temperature is measured graphically versus time on the meter. The dew point measurement is complete when the reading has stabilised.

FT-IR is a powerful tool for identifying and determining gaseous by-products. A sample of SF_6 is filled (1 atm) into a KBr glass gas-cell and placed in the direct path of an IR beam. IR radiation causes the bonds within molecules of SF_6 and each different decomposition product to vibrate. The energy absorbed by each bond is released at different characteristic wavelengths and detected. A Fourier transform then creates a vibrational spectrum by decomposing all the frequencies.

The spectrum is used qualitatively to identify the compound and quantitatively to measure the concentration.

Application

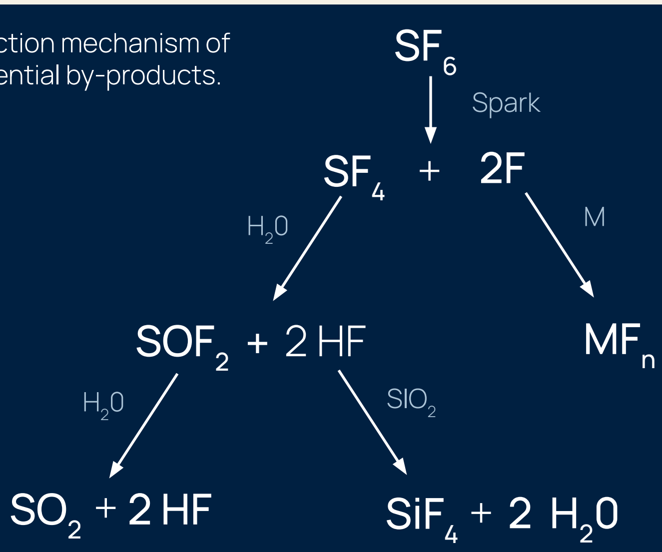
Contamination of SF_6 prevents the continued safe operation of the switchgear. Analysis of the ecomposition products in samples of SF_6 obtained from gas insulated electrical equipment is a diagnostic tool for the location of incipient faults in the equipment.

With the guidelines set by IEC 60376 and 60480, the analytical results allow the examiner to distinguish between acceptable and abnormal levels, where the abnormal levels can be caused by factors discussed earlier.

Cautions

The condition monitoring of SF_6 can be complex as not all perceived abnormalities are the same. There are different types of discharges under different conditions which unfortunately lead to different combinations of decomposition products (Figure 1.). It is important that the examiner obtains as much background information as possible from the equipment (e.g. electrode material, insulation material, lubrication material) and the nature / cause of the abnormality (corona or arc discharge and temperature) to better understand what type of fault gases are likely to be present. Fault gases are readily observed in the IR spectrum but can often be superimposed because of the similarities of their respective vibrational spectrums. Mathematical techniques such as derivative spectroscopy (built into the software) can de-convolute complex IR spectra.

Figure 1: Diagram showing the reaction mechanism of the decomposition of SF_6 and potential by-products.



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Sulphur Hexafluoride (SF_6) Gas Reprocessing

Reprocessing eliminates the need for disposal of waste gas through maximising the utilisation and life-cycle of your SF6 gas stream, resulting in a significant cost reduction and improved environmental compliance through the use of recycled gas. Powerlink's Laboratory Services can also evacuate your existing gas containing equipment and arrange for appropriate disposal.

Powerlink's SF_6 reprocessing plant has been designed to reduce environmental impact through the implementation of a safe and environmental friendly process for recovery, storage, conditioning and dispensing of SF_6 gas.

The reprocessing plant enables effective management of SF_6 gas recovered from insulated HV Gas Insulated Switchgear (GIS), bus ducts, circuit breakers and other devices or instruments containing SF_6 gas.

The contaminated SF_6 gas is recycled in accordance with the IEC 60480 standard for re-use and tested by a NATA accredited laboratory.

Reprocessing benefits

- Significantly reduce costs associated with disposal of waste
- Reduced need to purchase new SF_6 gas
- Reduction in overall organisational environmental impact

SF6 gas service cart functions

- Recover, reprocess and store SF_6 into on-board storage tank
- Evacuate customer equipment to < I Torr
- Recharge SF_6 gas from the storage vessel
- Transfer and consolidate SF_6 gas to and from standard SF_6 cylinders
- Reprocesses SF_6 gas from 40% to 98% SF_6 content to better than 99% SF_6

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Further information

Operating from our purpose-built laboratory and backed by over 30 years of experience in providing specialist oil, insulation and SF6 gas testing and diagnostic services.

Powerlink's oil testing and laboratory services provides a comprehensive transformer, reactor and high voltage oil and gas filled plant monitoring and condition assessment service.

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Powerlink acknowledges the Traditional Owners and their custodianship of the lands and waters of Queensland and in particular, the lands on which we operate. We pay our respect to their Ancestors, Elders and knowledge holders and recognise their deep history and ongoing connection to Country.

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