Oil sample management (Part 2)

by Tom Dalton, Rotek Engineering

The analysis of insulating oil is a highly specialised practice and needs to be preformed by skilled analytical chemists. Although the processes in a laboratory are highly repetitive it is always important to ensure the laboratory is capable of performing the analysis required.

It may be preferred to use a laboratory that has SANS accreditation. Further, a good track record or even better inter laboratory studies carried out will aid in ensuring accurate analysis and results. However, cost may play a major role in the choice, but choose carefully.

Interpretation and engineering

The interpretation of sample results is not a simple science. There are many twists and turns involved. Some results may require complex mathematical models and some results may only need a simple criterion.There are a number of factors that will influence results, and minimising these factors will ensure that results are true and correct, and represent the body of oil being assessed. Factors, like temperature fluctuations, oil processing, oil type, oil additives, gassing tendency and stray gassing can influence the analysis, and it is essential to have as much data on the unit as possible.

Most utilities have samples analysed for dissolved gas, dielectric strength, moisture in oil and acidity compounds as routine analysis. From these tests a general picture can be formed. However, if any of the parameter limits are exceeded further investigation should follow. We can break down the scope of analysis results into two main groups.

- Long term break down components
- Short term break down components

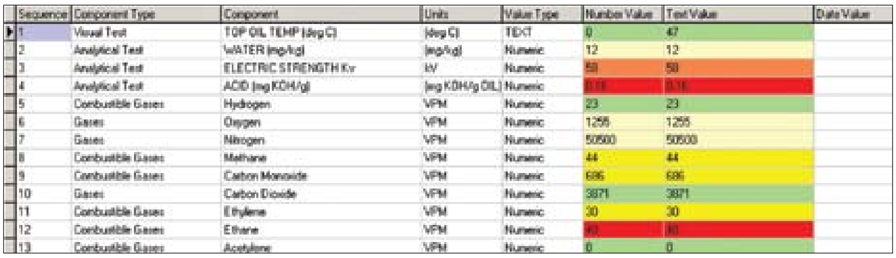
Long term issues will cater for the transformer's life extension and short term issues will be operational. For long term survival of a transformer it is necessary to focus on protecting materials that are most impacted while the transformer is in service. Materials such as the copper winding, the laminated steel core or even the tank materials have literally zero failures and will outlast oil and insulation materials by far (> 50 years). We need to look at protecting components that will fail due to their age or potential to cause the unit to fail unexpectedly. The "weakest link" is in the insulation materials of a transformer, which consists of two most critical components:

- Insulating oil
- Insulating paper ("kraft" paper used to insulate the transformers windings)

The insulating properties of oil can deteriorate, which could result in flash-over. This can easily be detected and rectified with minimal disruption to service delivery. Solid insulation failure, is less likely to be detected and can go unnoticed for long periods of time before a system disturbance causes the unit to fail. Solid insulation replacement requires long and expensive refurbishment work. Other damage can result if left unchecked, but this is less noticeable and rarely causes the unit to fail. However, this damage may reduce the transformers life and the asset owner may not reach the targeted return on investment.

Analysis	Derived or laboratory process	Specifications
Sludge	Chemical and Visual analysis	None
Tan Delta at 90°C	Analysis	<0,15
Acidity (mg KOH/g Oil)	Analysis	<0,05
Moisture (ppm)	Analysis	
Relative saturation (%RS)	Derived calculation	<5
Interfacial tension (mN/m)	Analysis	>32
Colour grading	Visual analysis	<2,5
DP based on furanic	Derived calculation	
Furanic content (mg/kg)	Analysis	Rate/year <50 µg/year
Estimated life remaining (%)	Derived calculation	

Table 1: Long term plant health indicators.



Sequence	Component Type	Component	Units	Value Type	Number Value	Text Value	Date Value
1	Visual Test	TOP OIL TEMP (deg C)	(deg C)	TEXT	0	47	
2	Analytical Test	WATER (mg/kg)	(mg/kg)	Numeric	12	12	
3	Analytical Test	ELECTRIC STRENGTH Kv	kV	Numeric	58	58	
4	Analytical Test	ACID (mg KOH/g)	(mg KOH/g OIL)	Numeric	0.16	0.16	
5	Combustible Gases	Hydrogen	VPM	Numeric	23	23	
6	Gases	Oxygen	VPM	Numeric	1255	1255	
7	Gases	Nitrogen	VPM	Numeric	50500	50500	
8	Combustible Gases	Methane	VPM	Numeric	44	44	
9	Combustible Gases	Carbon Monoxide	VPM	Numeric	686	686	
10	Gases	Carbon Dioxide	VPM	Numeric	3871	3871	
11	Combustible Gases	Ethylene	VPM	Numeric	30	30	
12	Combustible Gases	Ethane	VPM	Numeric	[illegible]	[illegible]	
13	Combustible Gases	Acetylene	VPM	Numeric	0	0	

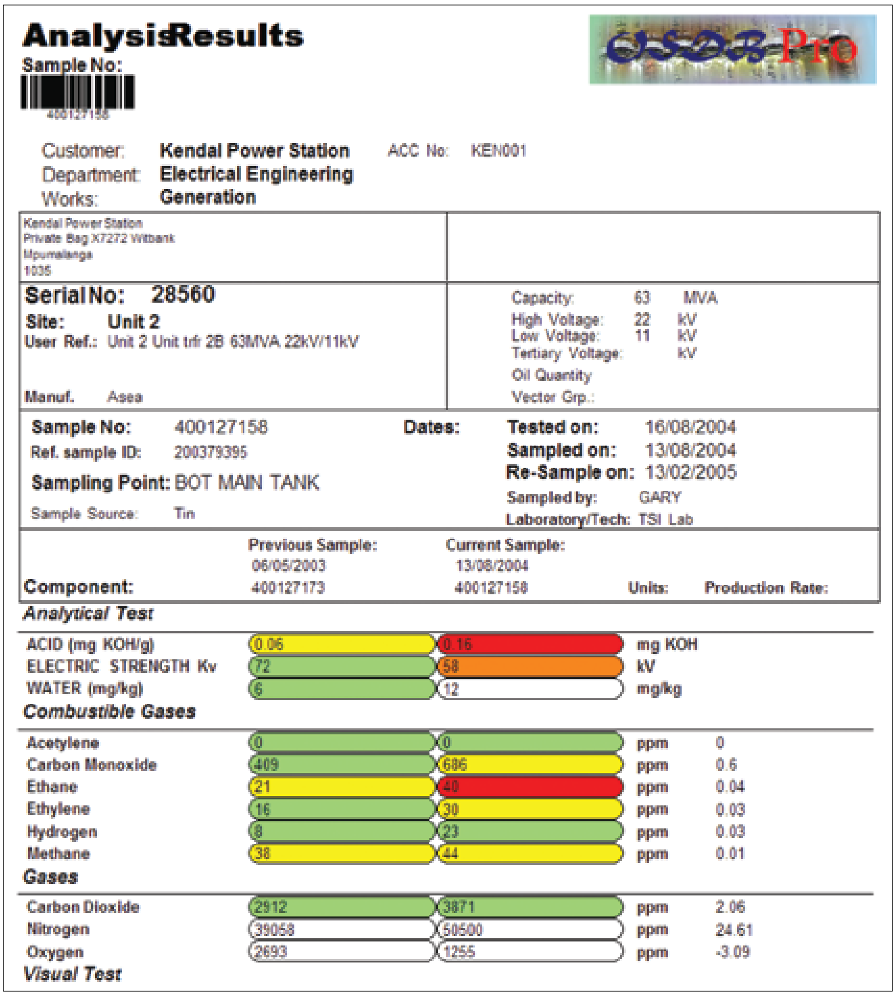
Fig 1: Results of analysis.

Short term break down of components is mostly observed as gassing which is a result of the oil being exposed to thermal or electrical stressing culminating in discharge faults. The reason they are classed as short term is that the situation can change within hours or seconds! The later will not be detected by normal sampling but where an online diagnostic tool is installed this may be picked up. Other than this the only other protection is the gas relay and electrical protection deployment.

Long term first line indicators include acidity (neutralisation index), dielectric strength and moisture. If these parameters fail – investigate further! There is barrage of tests that can assist in the determination of the extent and the severity of the decay. In Eskom this test list is known as the long term plant health Indicators (LTPHI). The analysis list is given in Table 1.

Note that the limit values are for in-service units.

Short term chemical analysis is mostly focused on the gases produced in the oil. If these gases are analysed routinely they can be of great assistance, but can be confusing. In most cases there should only be small quantities present in the sample. Added to this, oil and the produced gas are very susceptible to changing electrical and temperature parameters. The production of these analysed gases, being dependent on temperature, is used to detect thermal activities and assists in determining fault temperature and/or electrical activity. The gases produced can be broken down into three areas:



Analysis Results

Sample No:

400127158

Customer: Kendal Power Station ACC No: KEN001
Department: Electrical Engineering
Works: Generation

Kendal Power Station
Private Bag X7272 Witbank
Mpumalanga
1035

Serial No: 28560
Site: Unit 2
User Ref.: Unit 2 Unit trfr 2B 63MVA 22kV/11kV
Manuf. Asea

Capacity: 63 MVA
High Voltage: 22 kV
Low Voltage: 11 kV
Tertiary Voltage: kV
Oil Quantity
Vector Grp.:

Sample No: 400127158
Ref. sample ID: 200379395
Sampling Point: BOT MAIN TANK
Sample Source: Tin

Dates:
Tested on: 16/08/2004
Sampled on: 13/08/2004
Re-Sample on: 13/02/2005
Sampled by: GARY
Laboratory/Tech: TSI Lab

Component:	Previous Sample: 06/05/2003 400127173	Current Sample: 13/08/2004 400127158	Units:	Production Rate:
Analytical Test				
ACID (mg KOH/g)	0.06	0.16	mg KOH	
ELECTRIC STRENGTH Kv	72	58	kV	
WATER (mg/kg)	6	12	mg/kg	
Combustible Gases				
Acetylene	0	0	ppm	0
Carbon Monoxide	409	686	ppm	0.6
Ethane	21	40	ppm	0.04
Ethylene	16	30	ppm	0.03
Hydrogen	8	23	ppm	0.03
Methane	38	44	ppm	0.01
Gases				
Carbon Dioxide	2912	3871	ppm	2.06
Nitrogen	39058	50500	ppm	24.61
Oxygen	2693	1255	ppm	-3.09
Visual Test				

Fig. 2: Report on analysis.

Combustible gases:

- Hydrogen
- Methane
- Ethane
- Ethylene
- Acetylene
- Carbon Monoxide

Non combustible:

- Carbon Dioxide
- Nitrogen

Oxidation indicator:

- Oxygen

Each one except for carbon monoxide and hydrogen represents a temperature band.

- Methane low to medium temperature (150 – 250°C)
- Ethane medium to high temperature (200 – 700°C)
- Ethylene medium high to very high temperature (400 - > 100°C)
- Acetylene very high to extremely high (> 1000°)

Hydrogen is rather unique as it is present in all the above temperature ranges, but has a particular characteristic and is produced prolifically in partial discharge and arcing faults. Due to its size it can be used as an indicator to determine time span. In slow developing faults, typically general thermal over heating faults, hydrogen is still produced but disperses quickly (especially in open breathing units and less quickly in bagged or nitrogen blanketed units) and it can used to determine the rate (urgency) of the fault. A high concentration of hydrogen does spell "danger" and normally depicts a currently developing fault. Hydrogen is considered as a risk gauge.

Carbon monoxide, on the other hand does not indicate the thermal degradation of oil, but has a specific application and indicates mainly insulation degradation in both short term and long term. In the short term, any thermal fault that involves paper or board insulation will produce carbon monoxide (burning of cellulite based material) as a thermal degradation indicator. The production rates (ppm per day) are quicker and can be produced over a matter of days or hours depending on the severity. In the long term, it also indicates paper and board degradation, but the rate of increase will be slower (years) and can be used in conjunction with the production of carbon dioxide as a long term paper degradation indicator.

Carbon monoxide along with the carbon dioxide becomes a trigger to do further ageing analysis such as furanic analysis.

The other non combustible gases, carbon dioxide and nitrogen are not as well recognised in fault diagnosis. Both of these gases are naturally found the atmosphere and become an indicator of atmospheric contamination during the analysis. In recent years this is becoming less and less likely as the analysis techniques are improved.

Oxygen, although a naturally occurring gas, has become important in monitoring units that are either nitrogen blanketed or bagged (fitted with a conservator bag). High oxygen levels may indicate a leak in the system and the exclusion of oxygen to slow the oxidation process has been impaired.

There are a number of techniques that can be employed to evaluate the concentrations in both simple and complex ways using mathematical algorithms to assist in the interpretation of the results. All of these use the combustible gases. However, none of them can ever pinpoint an exact component failure or whether the unit is about fail. It is normally a combination of these techniques that assist in the determination of risk of failure. In some cases, only to instruct the operator that the unit has now failed and it is best not to re energise the unit!

The key to the above techniques is a good set of previous sample results. Comparison between samples is an absolute must to determine any resemblance of risk. The comparisons have rules:

- Two samples that have the same analysis (both have a full DGA analysis)
- Two samples that have same sampling point
- Relatively short duration between samples (2 to 7 days)
- What happened in between the two samples?
- Method of analysis (head space or vacuum)

As a starting point, check the sample results for any one of the gases being elevated or abnormal. A good guide for this is the California State University Guidelines or the IEEE guidelines.

These limits can highlighted for ease of recognition by colour coding the exceeded limits and may also adjusted to different classes of transformers. Fig. 1 shows an example of this technique:

It is quickly noticed that we have a problem and the report shown in Fig. 2 can show that we have a dangerous rate of production and that further investigation should be initiated.

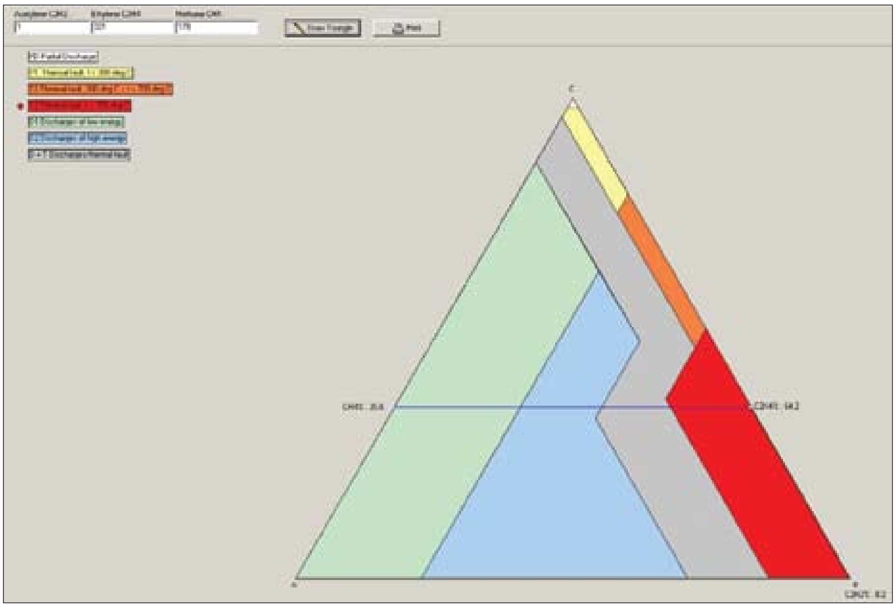


Fig. 3: Duval triangle.

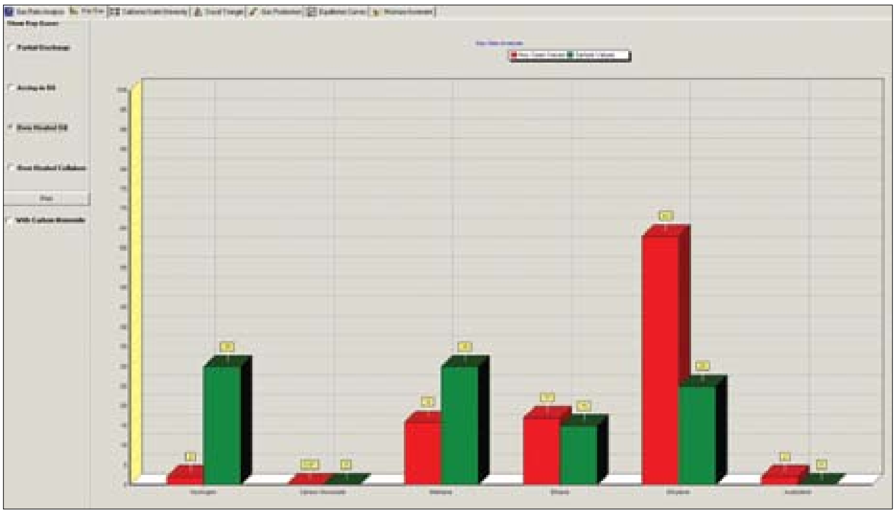
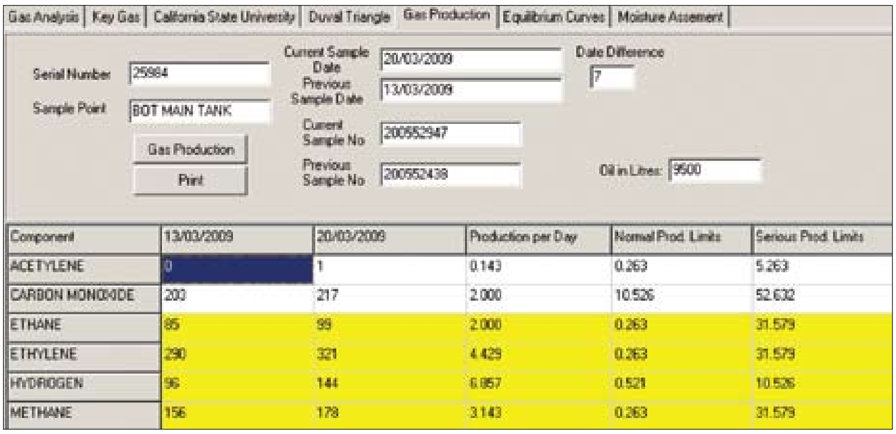


Fig. 4: Key gas method.



Component	13/03/2009	20/03/2009	Production per Day	Normal Prod. Limits	Serious Prod. Limits
ACETYLENE	0	1	0.143	0.263	5.263
CARBON MONOXIDE	203	217	2.000	10.526	52.632
ETHANE	85	99	2.000	0.263	31.579
ETHYLENE	290	321	4.429	0.263	31.579
HYDROGEN	96	144	6.857	0.521	10.526
METHANE	156	178	3.143	0.263	31.579

Fig. 5: Production rate analysis.

The results obtained should trigger the use of other methods. Note that any of analysis will dependant on good data quality and availability. Further analysis may include the following:

- IEC ratios (IEC60599)
- Roger's ratios (3 or 4 ratio method)
- Doërnenburg ratios

Also based on ratios is the Duval triangle as seen in Fig. 3

Key gas method, a more graphic method, can also be used. This method uses a bar graph that depicts a known norm with results from the analysis plotted alongside. If the pattern of the known values matches the values obtained from the analysis the genre associated with the pattern is the most likely interpretation. An example is shown in Fig. 4.

Other analysis that can be used is a simple summation of the combustible gases and the more complex algorithm, the Doble gas score.

Finally, if the above does prove an existing problem, the production rate analysis is a key to determine a level of risk. An example of this is shown in Fig. 5

Note: the above risk analysis detection limits are dependant on the volume of oil.

Depending on the analysis requested and the interpretation of these results, there is the final step in the process – the engineering, which involves taking a decision on the operation of the unit. In most cases operation will be normal and no action is required. This decision should be documented so that when an incident does occur there is a record of decision. A further step to this is using colour and marking these values in the data system. The benefit is that it can be seen at a glance which units are problematic and a full risk analysis as described earlier in the article could be implemented. This allows categorising units so that when the ever diminishing maintenance budget is sliced up you can base your apportioning decision on sound data and good engineering practices. An example is shown in Fig. 6

Re-scheduling

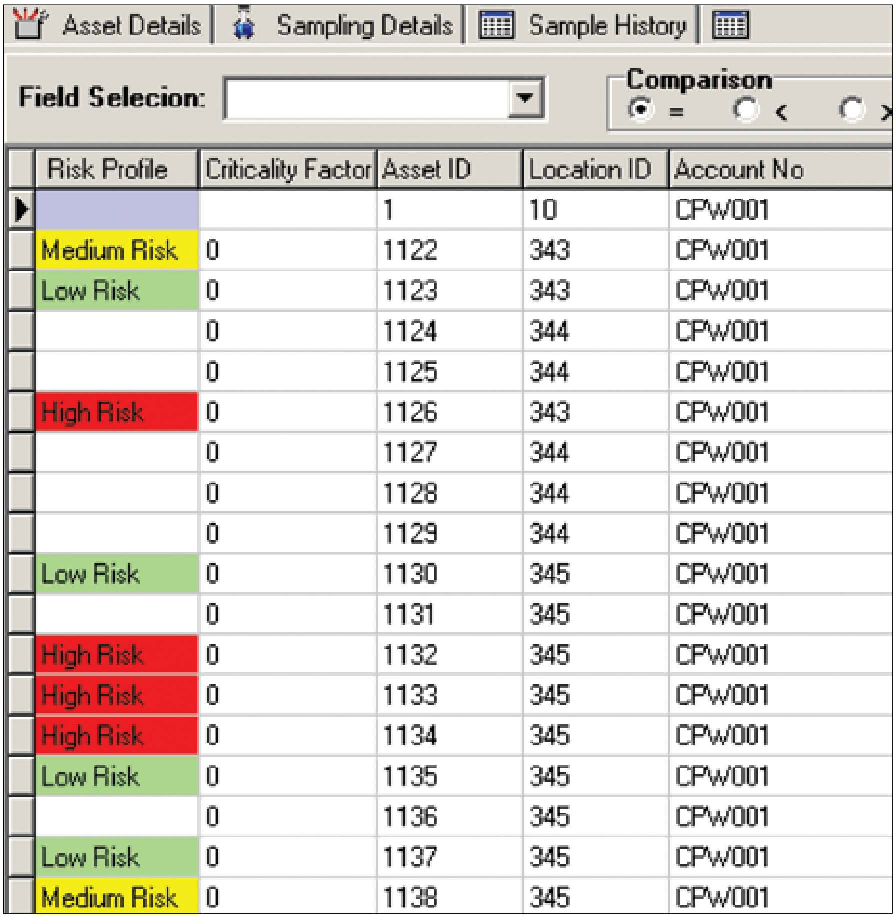
Following the guidance from the engineering decision the engineer/technician will re-schedule the next sample. Table 2 is a guide for making the re-scheduling decision and applying some basic rules to manage the risk levels.

Data storage and management

Sample management can be done in a spreadsheet environment for small operations (typically < 5 power transformers) but when the network becomes larger with more units and more samples are taken, and also including high risk units such as furnace, factory and process critical transformers it is recommended to use a well planned database system. There are some factors to consider prior to venturing down this road.

Laboratory kept data

The laboratory that analyses the oil keeps a database of all your sample results. However, check that this data is regularly



Risk Profile	Criticality Factor	Asset ID	Location ID	Account No
		1	10	CPW001
Medium Risk	0	1122	343	CPW001
Low Risk	0	1123	343	CPW001
	0	1124	344	CPW001
	0	1125	344	CPW001
High Risk	0	1126	343	CPW001
	0	1127	344	CPW001
	0	1128	344	CPW001
	0	1129	344	CPW001
Low Risk	0	1130	345	CPW001
	0	1131	345	CPW001
High Risk	0	1132	345	CPW001
High Risk	0	1133	345	CPW001
High Risk	0	1134	345	CPW001
Low Risk	0	1135	345	CPW001
	0	1136	345	CPW001
Low Risk	0	1137	345	CPW001
Medium Risk	0	1138	345	CPW001

Fig.6: Units categorised according to risk.

High Risk	Medium Risk	Low Risk	Out of service
DGA: Excessive gassing with one or more gases in the serious production per day category. The individual gas levels will be elevated or abnormal. TDCG above the 720 ppm level.	**DGA:** Elevated gases present. Above normal production per day on an individual gas. TDCG below the 720 ppm level.	**DGA:** All gases are normal. No elevated gases present. Production rates (production per day) are below the normal limits.	**DGA:** Not performed on this category.
Dielectric strength: Below 30 kV for class O and A transformers. Below 20 kV for class B and D transformers. If not influenced by moisture proceed to have the oil tested for Tan δ @ 90°C and particle analysis.	**Dielectric strength:** Below the recommended specification. Resample if necessary and check moisture content.	**Dielectric strength:** Above the recommended specification.	**Dielectric strength:** Above the recommended specification for out of service transformers.
Moisture content: Above 3% moisture in paper where the transformer is running at temperatures above 35° C. Further, the dielectric is below the specified limits. Further testing is suggested (IFT).	**Moisture content:** Above 2.5% moisture in paper where the transformer is running above 35° C. Further, the dielectric is still above the specification.	**Moisture content:** Below 2.5% moisture in paper where the transformer is running above 35° C. The dielectric is as prescribed in the dielectric block.	**Moisture content:** Due to the oil temperature being low there is little or no practical application of moisture in paper value. Thus the oil must follow the new oil specification, i.e. >10 ppm.
Acidity: Exceeds the specified limit. Should be considered in conjunction with dielectric strength and moisture and with special consideration with the degree of polymerisation of the paper.	**Acidity:** Approaching the specified limit for in-service transformers (80 – 90% of the limit). Should be considered in conjunction with dielectric strength and moisture and with special consideration with the degree of polymerisation of the paper.	**Acidity:** Below the specified limit for in-service transformers (below 80-90% of the limit).	**Acidity:** Not performed in this case and should be in line with new or regenerated specifications.
Degree of polymerisation: Below 200 DP – further testing may be encouraged if the unit is of strategic nature. Regular sampling is paramount. (3 months o	**Degree of polymerisation:** < 400 – 350 DP – the asset is reaching the end of its life and special note must be taken of the dielectric strength and moisture content.	**Degree of polymerisation:** > 400 DP paper is still healthy. Check that the limit of 50 ppb is not exceeded.	**Degree of polymerisation:** Not performed on this category.

Table 2: Scheduling decision table.

backed up and that the back is kept off site. Further, ensure that you can get full access to the data if you would like to use another laboratory. Be aware of laboratories that lock you into their data system.

Asset owner kept data

The facility keeps its own data. This could initially be expensive, but the data is available locally and immediately, which is seen as an advantage. On the negative side these data systems need to be kept up to date, which takes effort and dedication.

Contractor kept data

The contractor employed to take samples keeps a database of the samples. Again, check that the database is regularly backed-up and the data is kept off site. Due to contractors being changed after contractual obligations are completed, there is a risk of losing your data when contracts change. Ensure that you are able to extract the data from their system, so that when the contract is concluded and a new contractor is commissioned you can access your data.

Finally when talking about data history, please note that it is meant in the electronic format and not on paper! Ensure it is written in a format that your IT department can read (electronically). Recommended formats are: CSV files (comma separated values), text files or Microsoft Excel, but be aware of XML files and other formats as these are more difficult to import into commonly used systems. Microsoft Access (a relational database) has been widely used as a desk top database tool and is relatively easy to use for this purpose. There at least two South African systems (in MS Access) that have been written with oil sample management in mind and there also other systems from the USA and Canada. Lastly, be aware that MS Access does not work well over a wide area network (WAN) and in this case an executable (exe) program (built in VB, C++, C#, Java or Delphi) using a stable database system (MS SQL 2005/2008, Oracle (expensive), Borland Interbase or other main line relational database systems) may be better suited for these types of environments. Note that the later systems by programmers and compiled into an executable application.

Conclusion

If you have been involved in the management of samples in past or about embark on implementing a sample process, read as much as you can about the topic. Remember that the outcome is only as good as the sample that is taken. Note that this article can only outline some of the issues, and the interpretation of results and risk management of a fleet of transformers can be complex and challenging task. A well designed database system goes a long way to easing the management of the process.

References

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