Free Breathing Power Transformers – or NOT!
"Corrosive elements in oil causing transformers to fail"

Author & Presenter: Hermie Visser MSc. Eng.

1. Introduction

Power Transformers are representative of a large capital investment in utilities. The service life seems to be reducing and failures are occurring at perceived midlife. This place a bigger emphasis on life extension techniques.

Corrosive elements like sulphur were found in transformer oil whilst doing root cause analysis on failed units. This opened a new field of investigation into types of insulating oil and application.

2. Conclusion

The conditions inside the tank of a Power Transformer are representative of a large chemical reactor and almost provide a closed loop system. When one or more components are changed then the system will react to cause alternative chemical reactions.

Identify transformers that may be affected and consider the risks. Cigrè (and other similar bodies) are studying this topic and effects on long term applications. Study the results of these groups and decide on local application.

Consider sealed transformers running at high temperature to be at risk until tested.

3. Background and problem description

Failed Power Transformers are analysed in detail to determine the root cause of the failure. This information and findings are then used for implementing methods to prevent failures in similar apparatus. During the last five years it was found that the failure patterns did not fit the known root causes, which initiated worldwide investigations to find out if they were attributable to corrosive sulphur.

Blackened materials and foreign deposits were found. Further investigations showed that the oil contained corrosive elements from sulphur present in the oil. It was then established that since the year 2000 transformer oil supplied in South Africa contains higher values of sulphur, both corrosive and non-corrosive. The bulk of oil specified for Power Transformers were Nathenic Un-inhibited oil. The application for this oil would be in free breathing equipment.

Failures of this nature started in step-up Power Transformers and Reactors then it seems to cause faults in tap changers and step-down Power Transformers.

4. Sulphur

4.1 Sulphur in transformer oil

Sulphur is a natural element contained in crude oil. The sulphur contained is made up of various types of elements of which some is bad and some are beneficial for stability. Although the sulphur is contained as a very small percentage, it can never be zero.

4.2 Sulphur in manufacturing materials

Sulphur is also contained in materials used in the construction and manufacturing process. Although they may be in smaller quantities and even have smaller surface contact area, they can not be excluded. Examples of these are:

- Some glues used in the paper wrapping
- Types of gaskets
- Catalyst and hardener products
- Copper itself contains small amounts of impurities
- Paints

Cognizance should also be taken of the machines and hoses used during the manufacturing process to ensure that sulphur is not introduced.

4.3 Refining process of crude oil

The quality of transformer oil can be traced back to the exact place on the earth where it has been sourced from. The natural oil forms the basis and its characteristics will remain for the life of the oil. Great care is taken by the refiners to select only certain crude oils to form the basis of transformer oil.

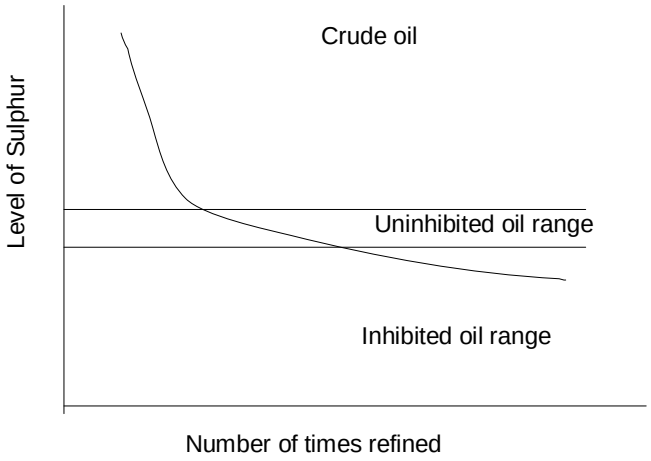
Unrefined oil contains these elements: [1]

- Elemental Sulphur
- Mercaptans
- Sulphide
- Disulphides
- Thiophenes

Hydro and Acid methods are used to remove sulphur during the refining process.[2] The remaining sulphur will be in the order 0.05% - 0.6%. From early studies it is concluded that **elemental sulphur** is the most corrosive form of sulphur.

By repeating the refining process will remove more sulphur. However, this will add to the cost of the end product and it will remove the natural inhibitors, which we want in the oil. The question is thus, how can we remove the “bad” elements and keep the “good” elements? A simplistic graph is shown below to indicate the balance between the sulphur level and the number of times the oil is refined.

Simplistic graph to show effect of multiple processing



5. Power Transformers

5.1 Transformer application

In general it can be said that South Africa uses uninhibited oil. Sub-transmission and Utilities use Power Transformers (up 200 MVA) that are mostly free breathing. In literature regarding the preservation of Cellulose Paper it was cited that acid (from the oxidation process) will damage the fibres of the paper.

In an attempt to preserve the Cellulose Paper the transformers were “sealed” from the outside surroundings by placing a diaphragm or “bag” in the conservator. Two benefits were created by reducing moisture ingress and to remove all contact with oxygen. The lack of both these elements would increase the life of the Cellulose Paper. In order to achieve these benefits the transformers of 40MVA and larger were fitted with sealed breathers from about 2003.

5.2 Factors increasing corrosive activities

If we accept that sulphur is always present in transformer oil, we have to look at the causes for it to be more corrosive. The three elements that are cited as being the key players in causing problems in transformers are:

- Transformer oil containing high volumes of reactive elements. (Elemental- and Mercaptans sulphur)
- Transformers with reduced oxygen levels
- High temperature spots inside the transformer

5.3 Test methods

There are standard testing methods, but some are now modified for improved results. Here are a few examples:

- ASTM D1275 19 hours at 140^{o} C
- ISO 5662

- DIN 51353
- ASTM 3120

5.4 Corrosive Sulphur reacting with copper

The copper used in transformers is not perfect copper. It contains some impurities. The sulphur in the oil may react with these even more than with the copper itself. When the copper is covered by a varnish, this may be sufficient to stop or reduce the chemical reaction.

However, where the copper is in direct contact with the oil and there is high temperature, then corrosive reaction will take place. From this the by-product Copper Sulfide will be formed which will float in the oil and deposit between the windings. Copper Sulfide will reduce the electric strength of the insulation causing inter-turn faults.

5.5 Corrosive Sulphur reacting with silver

At least one case was reported of a tap changer failure that may be attributed to corrosive sulphur. Silver is more affected by corrosive sulphur than copper. Again there is a requirement to have high temperature present. The case as reported involved a silver terminal in the tap changer that was hot. Flakes formed on the silver and it is suspected that these flakes dislodged during at mechanical movement and bridged the insulation gap causing a short circuit.

6. Alternative oils and its logistics

When alternative oils are introduced then a lot of logistic and maintenance aspects will be highlighted. A few will be mentioned in the next paragraphs, but this is by far not exhaustive.

- Separate storage facilities will be required as well as separate machines for maintenance.
- New methods to test and analyse routine oil results, since the production of gases may have different results.
- If the oil has an inhibitor then that needs to be monitored and adjusted.
- If the new oil is inadvertently mixed with old oil what effect will that have?
- Are the new oil or its additive toxic and what precautions will staff needed to take?
- Environmental issues and risks.

7. What actions and alternatives are available?

How can a utility manage the transformer oil with this new information? Worldwide study groups are busy with research into this and will make their findings known. Risk is a driving factor and therefore the very large step-up transformers will get more focus. Secondly, large units with sealed breathing systems will get attention.

Always check and confirm with the transformer manufacturer that the oil to be used in a transformer is accepted. Let's discuss a few available options.

7.1 Free breathing units in service

Continue to test the acid level on a regular basis and use regenerating techniques to reduce the acid level in the oil. Fuller's Earth type of clay is successful with this operation.

7.2 Sealed transformers in service

Utilise standard oil sample test results to verify the gas (Dissolved Gas Analysis) produced in the transformer and if there is any indication of hot spots in the transformer. Add these transformers to the list of transformers to be considered as high risk installations. Test these transformers for corrosive sulphur and form a contingency plan for the ones that contain corrosive sulphur.

7.3 Use of inhibited oil

This type of oil is used by some international countries when applied to sealed transformers. The gassing tendency is different and a new interpretation is used. The sulphur content is very low due to the super refined product. This means that the natural inhibitors are removed, hence the need for the inhibitor to be added. The level of inhibitor needs to be monitored and corrected when required.

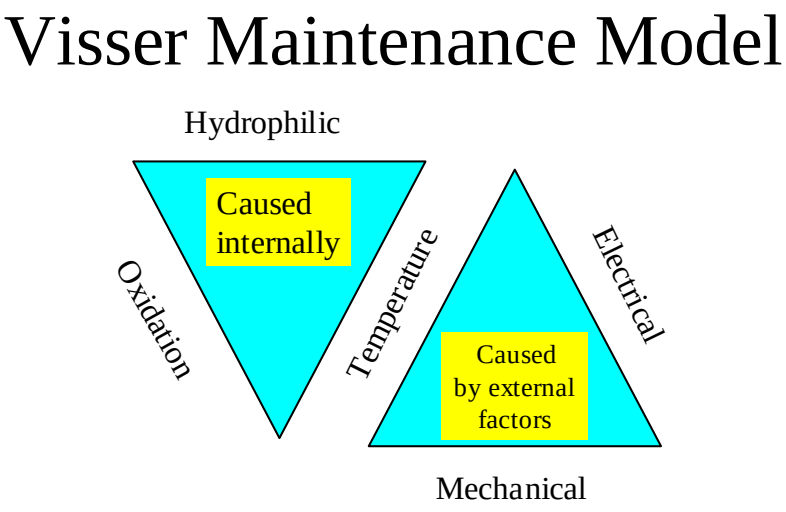
7.4 Use of a passivator

When passivator is added to transformer oil it will stop the corrosive action. It can not undo any damage that has occurred. The long-term affects of this needs to be studied, not only on the oil but also all other items in the transformer. Further research in this field is required before its long term impact can be accounted for.

8. Summary

The negative effects pertaining to transformers where corrosive sulphur is present is a relatively new phenomena and it needs to be understood in order for long-term maintenance activities to take effect. When one aspect in the transformer is changed it affects something else in the chemical reaction. When applying a method to deal with this corrosive sulphur, also consider the way that the balance will be disturbed.

Is it better to deal with the acid created from the oxidation process or results of corrosive sulphur?



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