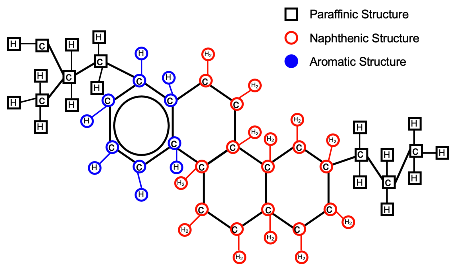
CORROSIVE SULPHUR IN TRANSFORMER: A SERIOUS PROBLEM?

In recent years, it has been reported a sudden and unexpected cases of power and distribution transformers failures causes by corrosive sulphur. Although the oil passes the standard corrosive sulphur test, the sulphur compound used as normal natural additive in the oil and non-reactive at normal operating conditions may reactive at extreme conditions in the transformer. The problems caused by corrosive sulphur, why the problem has resurfaced, detection of corrosive sulphur in transformer and remedies suggested to prevent further destruction was featured in this article.

INTRODUCTION

Insulating oil in transformer served as dielectric material to insulate different potential parts and coolant to dissipate the heat from core and winding during transformer energisation. The oil is manufactured from mixture of basic saturated hydrocarbon; paraffin, naphthenic, aromatic and sulphur compound. Sulphur is commonly found in crude oil sources as it comprises almost 0.05% of the earth's crust. Not all sulphur is corrosive, some can actually aid in the oxidation stability of the transformer oil and may also act as metal passivators and deactivators reducing the catalytic effect on oil oxidation in transformers. Sulphur may also exist in copper, insulation paper, glue and rubber gaskets used in the manufacture of transformers.



Structure of mineral oil

Group	Reactivity
Elemental sulphur	Very reactive
Mercaptans	Very reactive
Sulphides	Reactive
Disulphides	Stable
Thiophenes	Very stable

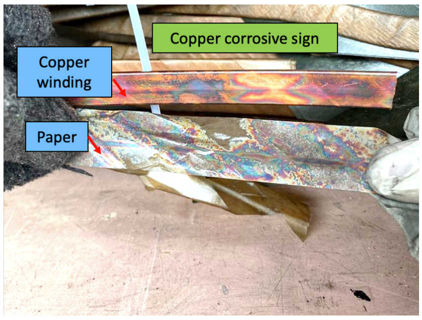
Sulphur compound in insulation oil

There are several sulphur compounds found in refined transformer oil. Some are corrosive or reactive and others are more stable and less reactive such as Thiophenes. Nevertheless, experience has shown that non-corrosive sulphur can become corrosive after being exposed to elevated temperatures on hot metal surfaces and thus produce metal sulphides. This would corrode the material surface and could detach and become nuclei for discharge and gas inception. The oil with low sulphur contents may not be a concern as the quantity of corrosive sulphur compounds produced may not be sufficient enough to cause extensive damage.

CORROSIVE SULPHUR EFFECTS

The primary reaction of corrosive sulphur will caused corrosion of metal surfaces especially exposed copper or silver surfaces. The contacts that are overly contaminated with what appears to be a build up of carbon, in reality is a sulphur sulphide. The effect of a corrosive or reactive sulphur attack on a metal conductor do not always result in a black coating. In some cases, a silver coating or a silver discoloration of the conductor surface may occurs. In addition, the sulphide formed at the metal surface can also migrate to the paper insulation. This will causes a reduction in dielectric strength of the paper insulation and result in arcing between two or more turns or disks which lead to catastrophic failure of the transformer.

Flake of sulphur sulphide at tap changer contact

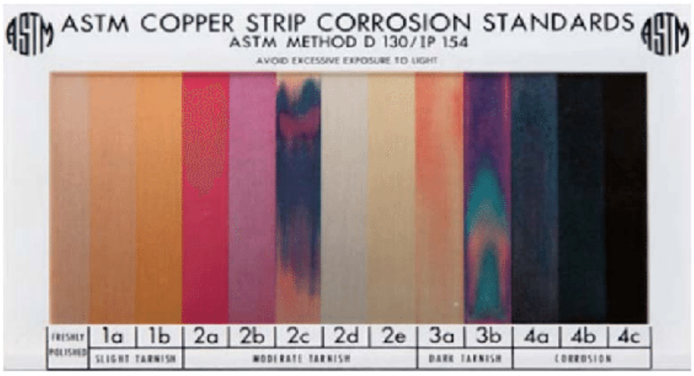


Evidence of sulphide at copper surface and insulation paper

CORROSIVE SULPHUR DETECTION

Recent transformer failures are reported due to presence of dibenzyl disulphide (DBDS) and therefore appears to be a predominant role in the corrosion process. DBDS is identified as a major sulphur compound and present in approximately of 90% of the insulating oils. To date, the industry not yet to identify a successful method to test for the extent of damage incurred by sulphur corrosion without disassembly of the transformer. Therefore, testing of insulation oil to determine corrosive sulphur content prior to use in transformer is critical to avoid the corrosive sulphur issues from the start.

The traditional test for corrosive sulphur in transformer oil follows the ASTM-D-1275A. In this test, the oil is exposed to a copper strip and heated to a temperature of 140°C for 19 hours in a sealed environment. The test is pass or fail based on the amount of deposition and discoloration of the copper surface. In more stringent test method called ASTM-D-1275B, the sample is heated to temperature of 150°C for 48 hours. This aggressive test is able to better identify corrosive sulphur in oil due to its higher temperature and longer duration. This may be because some sulphur compounds breakdown and create more reactive compounds when exposed to intense heat. Additional tests known as "Covered Conductor Deposition" may also be used to check for the presence of corrosive sulphur. This test focuses on the deposition of copper sulphide in the paper insulation. The oil is exposed to a conductor wrapped in kraft paper and heated to a temperature of 150°C for 72 hours and then visually inspected for copper sulphide deposits.



ASTM Copper Strip Corrosion Standard used to evaluate oil for corrosive sulphur

CORROSIVE SULPHUR MITIGATION

As transformer is the most critical asset in any electrical network, carrying out mitigation actions against the corrosive sulphur and DBDS deems essential to prevent the risk of catastrophic failure of in-service transformer. Therefore, the asset manager are needed to evaluate their own level of risk and adopt an appropriate strategy to manage it.

There are several mitigation techniques that can executed by the asset manager. However, there is no single solution that fits all, and several operational and strategic aspects needed to be taken into account while selecting the mitigation actions.

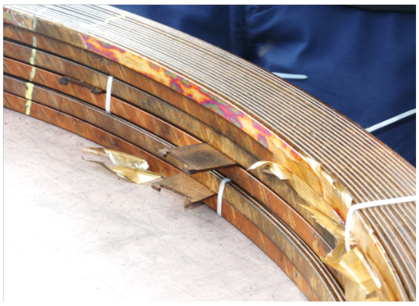
Mitigation Technique	Pro and Cons
‣ Reduce transformer operation temperature	‣ Sulphur sulphide formation increase with temperature. Therefore, increased cooling efficiency can aid in slowing the process of sulphide deposition. However, it will not stop the process all together.
‣ Adding passivator to existing oil	‣ Most widely used and the most cost effective technique owing to the simplicity and low time required for execution. ‣ Metal passivators forming a monomolecular layer (a coating on the surface) that blocks copper involvement as a reactant in the copper sulphide formation and hinders copper catalytic activity as an oxidation catalyst. ‣ However, it does not focus on removal of DBDS and can be considered as a temporary solution. ‣ Passivator will decrease in concentration over time as it reacts with copper surfaces and is degraded by heat and oxygen. ‣ Stray gassing may sometimes occur after the addition of a passivator to the oil.
‣ Oil replacement	‣ The best option to prevent further damage if the oil fails the CCD, 1275B, and 1275A tests, indicating the corrosive sulfur is fairly aggressive and deposits have likely already started to degrade the insulation. ‣ Expensive process on oil replacement.
‣ Oil reclamation	‣ Less cost compare to complete oil change ‣ Eliminates or reduces soluble and insoluble polar contaminants, degradation products and also corrosive sulphur compounds from the aged oil by chemical and physical processing using fuller's earth. ‣ Efficiency of removing DBDS depends on the reclamation machine and time taken. The oil may become more corrosive after oil reclamation process.
‣ Removal of DBDS or mercaptans	‣ New method to destroy DBDS and mercaptan compounds in oil ‣ However, it is still a new process which is under development.

TRANSFORMER FAILURE BY CORROSIVE SULPHUR

The transformer was 20 years in operation and originally supplied with inhibited oil. The transformer was tripped on bucholz relay and further analysis shows high combustible fault gases and failed on turn ratio, excitation current and sweep frequency response analysis measurement. The oil quality analysis indicated high DBDS content. The transformer was dismantled and un-tank and the winding was inspected for fault identification. The internal inspection shows inter-turn fault on one phase of the transformer windings.

Internal inspection of transformer winding shows inter-turn fault

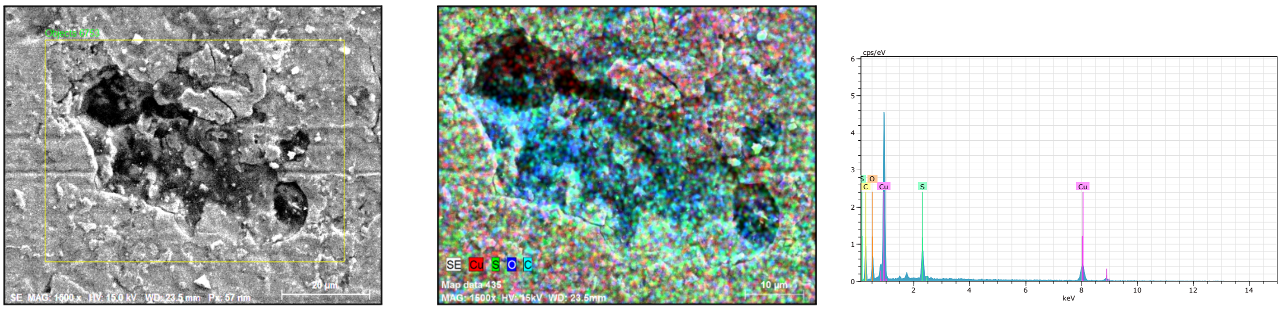
The teardown examination revealed a copper corrosion sign in which a discoloration or rainbow colour and black mark was observed at the inner copper winding. The sulphide was also found deposited on insulation paper and this is one of the factors that has reduced the dielectric strength of kraft paper and eventually short circuited the winding conductor.



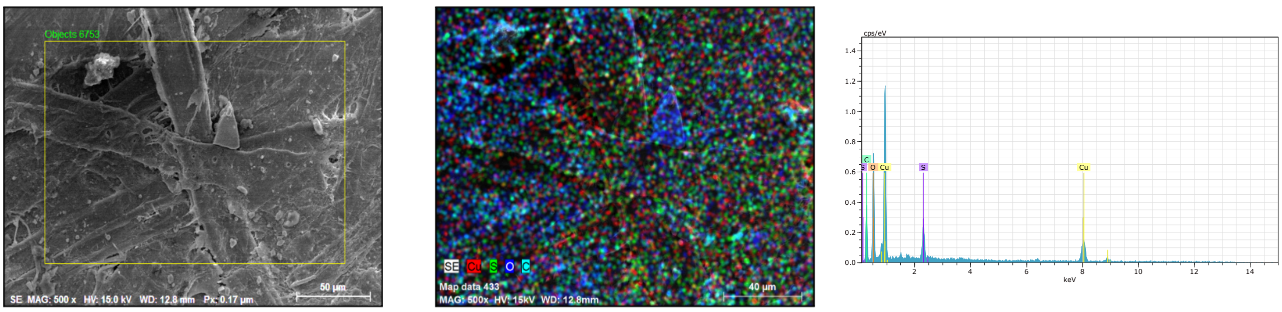
Sign of copper corrosion

Short circuit of winding conductor

Further analysis using Energy Dispersive X-Ray (EDX) to identify the elemental composition of materials discovered a presence of sulphur at the area of short circuit winding; both copper conductor and insulation paper.



EDX analysis on winding copper conductor



EDX analysis on kraft paper insulation

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A New Approach for DGA Interpretation of In-Service Power Transformer

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