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TRANSFORMER LIFE CAN BE EXTENDED

" Dr B PAHLAVANPOUR "

" Dr H HABIBOLLAHI "

INTRODUCTION :

While transformer manufacturers prepare elaborate insulation and maintenance manuals regarding their product, and give specific and generalized information for the transformer user, they approach the problem from a client customer background. Day to day decisions need to be made that will result in extending the life of the transformer beyond the twenty to thirty years of normal life expectancy. Therefore, we will approach this problem from a fundamental and elementary basis, and establish guidelines for the transformer maintenance engineer to follow. Many of the materials used in the manufacturing of the transformer are detrimental to many of the other materials. The result of this is that the transformer is designed to "self destruct". For example, oil impregnated paper is the basic insulation system. Mineral transformer oil is used to protect the paper and enhance its mechanical and dielectric strength. However, the Kraft paper acts as a catalyst to form acids in the oil, these attacking and destroying the paper. It is clear that the objective of a maintenance program for the transformer should be to control the rate of "self destruction" since this phenomenon cannot be eliminated, but controlled.

Insulating oils used in air-breathing transformers absorb oxygen to the point of saturation. Even in sealed transformers, it is usual to find some oxygen in the oil as the result of leaks or imperfect seals and diaphragms. In the presence of metallic compounds and high temperatures, the oils oxidise and eventually lose their dielectric stability as a result of the polar compounds (acids) and sludge formed. The oil thus becomes corrosive and the solid particles forming the sludge are deposited at different places in the transformer, building up sediment that reduces the oil's heat dissipation capability and electrical properties. Moreover the increase in soluble acidity and sludge can lead to serious transformer malfunctions.

The standard procedure used by electrical utilities for reclaiming aged oils consists of filtering through a polar absorbent known as Fuller's Earth. This procedure is normally applied as soon as the interfacial tension of the oil approaches 20 mN/m, the soluble acidity is close to 0.15mg KOH/g oil, and the oil has a poor resistivity. At this stage oxidation is pronounced with a high concentration of polar compounds (acids), and the oil has reached its saturation level. Reclamation removes the acidic molecules and sludge, but a large proportion of non acidic polar compounds (alcohols, aldehydes, ketones, ethers etc) remain in solution. These products are acid precursors, and if they remain in the oil when it goes back into service, they can accelerate its oxidation rate. Despite the addition of the inhibitor, reclaimed oils usually have a service life of one half that of new oil.

Throughout this paper various terms and definitions have the following meaning.

RECLAMATION - The restoration to usefulness by the removal of contaminants and products of degradation such as polar, acidic or colloidal materials from used electrical insulating liquids by chemical or absorbent means.

RECONDITIONING - The use of primary refining processes on used electrical insulating liquids to produce liquids that are suitable for further use as electrical insulating liquids.

ADDITIVE - A chemical compound or compound added to an insulating fluid for the purpose of imparting new properties or altering those properties when the fluid already has.

INHIBITOR - Any substance that when added to an electrical insulating fluid, retards or prevents undesirable reactions.

OXIDATION INHIBITOR - Any substance added to an insulating fluid to improve its resistance to deleterious attack in an oxidizing environment.

DESLUDGING - A process whereby oil in a transformer is circulated through a regeneration plant and heated to above 80 degrees C, such that it becomes an effective solvent for its own decay products ie. sludge.

OIL RECLAMATION (REGENERATION) :

Reclamation defined by BS 5730 as, "A process which eliminates from the oil all contaminants, insoluble and dissolved, to attain an oil with characteristics similar to those of a new product".

In the past it was generally accepted in the industry that mineral insulating oils had a limited useful life. Due to the formation of acids and insoluble sludge by the process of oxidation which resulted in the oil becoming unfit for further service. When acidity or sludge reached some arbitrary value, the oil was removed and replaced by new oil.

A number of papers have reported the reclaiming of damaged insulation oils (1). The processes used were re-refining with chemicals (2), activated alumina or Fuller's Earth (3-4). The sulphuric acid treatment generally involves mixing the damaged oil with two or three percent sulphuric acid and separating the oil from the acid. The oil is then mixed with silicate of soda and passed through the Fuller's Earth tank. The oil loss is about six per cent and the process is very slow and time consuming. One danger involved in the process is storage and handling of the sulphuric acid.

Fuller's Earth is the material most frequently used for refining oils. This is a naturally occurring clay with a fairly high surface activity. This material can be used in its original state or processed by acid wash or steam treated. The processed clays are more active but also more expensive. Activated alumina is an efficient absorbent for impurities found in oil. It has some advantages over Fuller's Earth such as mechanical stability and easy reactivation. However, if used materials are not regenerated for reuse, this also becomes an uneconomic process.

Reclaiming insulationg oil in energised transformers can offer several advantages (5-6). There is no need for transformer outage, trasport or disposal of old oil. The employed method involves circulation the oil from the transformer to the purifier and back again to the transformer for a period of time, until the oil in the transformer reaches a satisfactory condition. This is governed by testing electrical, chemical and physical properties of the oil. It has been claimed that using this technique can increase the life of a power transformer (6).

TRANSFORMER DESLUDGING :

A heavily sludged used oil, completely unfit for further use in the transformer, contains at least 80% of usable hydrocarbons. Therefore, it can be re-used if the oxidized products are completely eliminated. Pure hydrocarbons are not easily oxidized under normal conditions (7). Sludge is the final step of oil deterioration. Sludge is soluble at lower concentration in naphthenic oil, but eventually precipitates out of solution and forms a heavy tarry substance which adheres to the insulation and the side walls of the tank and lodges in ventilation ducts.

The most serious effects of the sludge when formed in the cellulose is shrindage of the insulation. As a result of this the transformer loses its ability to absorb shock loading. The mechanics of the sludge formation have been studies by ASTM and it has been concluded that the process of oil oxidation consists of two main cycles:

a) The formation of soluble products such as acids, beginning as soon as the oil is put into service.
b) The change of soluble oxidation products into insoluble compounds.

The precipitated sludge on the parts of the transformer will further oxidize and become insoluble. Sludging takes place periodically rather than continuously. There is a strong relationship between oil acidity, interfacial tension and sludge content.

There are several approaches to the desludging of a transformer. These include reconditioning the oil, replacing with new oil, reclaiming the oil and hot oil cleaning Reconditionint the oil removes moisture and particles. Although it can reduce further deterioration of the oil, it cannot desludge the transformer.

Oil replacement can be achieved by draining out the used oil, flushing the core and coil, and replacing with new oil. The trapped oxidized oil in the cellulose will leach out and contaminate the new oil in a short period. A small quantity of badly oxidized oil can ruin very large quantities of new oil. Furthermore, changing oil does not remove the depository sludge on ghe core and coils. Reclamation of the oil removes oxidation product from the oil but will not remove the sludge from the unit.

Hot naphthenic oil can dissolve the deposited sludge on the interior of the trasformer. This can be achieved by circulation hot clean oil into the top of the transformer while the transformer is energized. To maximise the desludging process it is important that it is performed on an energized transformer, since the heat from the core will help to dissolve the sludge in the oil. The contaminated oil is then removed from the bottom of the tank of the transformer, reclaimed and returned into the top of the transformer. This process is performed in a totally closed manner.

The reclamation of the oil produces contaminated Fuller's Earht. This is a waste product which must be disposed of in a proper manner. This is usually achieved by land fill or incineration. Landfill operators are becoming sensitive to the oil content of the material they accept. The incineration method is very costly and must be performed at a high temperature. Therefore reactivation of the clay is preferable.

OIL RECLAMATION AND TRANSFORMER DESLUDGING :

A mobile Oil Regeneration unit (MRU) type R5000-RM mounted on a double axle, double whell semi-trailer, is used for in-situ transformer oil regeneration and desludging. The MRU consists of two main elements: an oil regeneration section and an oil purification/degassification unit. The unit uses inherent oil from the live transformer plus own heater to dissolve sludge, pick up moisture, acid and particulate contaminates whilst feeding clean, dry oil into the transformer. The MRU was connected to the on load transformer. Dirty oil was continuously removed from the bottom of the main tank of the transformer and after regenertion entered into the transfomer from top hose connection to coolers.

The oil regeneration section basically removes acidity, water and sludge and corrects the colour of the oil by force percolation of the oil through a series of activated "structured clay" columns. Unlike other commercially available plants which have to dispose of the saturated clay beds after each processing cycle, the R5000-RM has the built in facility to reactivate the clay in the columns automatically.

The first stage of processing lasts for approximately 24 hours. Then the performance of the clay begins to reduce (the first indication being a darker colour to the reprocessed oil). The plant then automatically switches to reactivation. After a 14 -16 hour period, the plant is again ready for a new regeneration cycle. For lightly contaminated oil, the regeneration part of the cycle can be extended to maximise the effectiveness ot the columns thereby effectively increasing the capacity of the plant.

Degassing, moisture extraction and filtration take place in an independent section of the MRU. The purification section can operate continuosly. simultaneously and independently of the regeneration section thereby maintaining contionuos circulation of the oil threough the heaters and filters of the MRU.

The purificaiton plant combines degassing, moisture extraction and filtration. Unlike the processing plant, it can be operated 24 hours a day. This technique is used in other reprocessing equipment except the foaming of the oil in the vacuum chamber is not controlled by the reduction of the vacuum applied to the oil by via an automatic vacuum. The flow rate with an energised transformer is limited to a maximum of 2500 Litres/hr. The number of cycles is dependant on the degree of the oil oxidation and contamination. Desludging usually takes place at a higher temperature than oil regeneration. There are two important criteria for desludging to take place. The first is the temperature of the oil in circulation through the MRU which must be over its aniline point of about 78 degrees C. Secondly, in order to redissolve the sludge the oil supplied to the transformer during circulation must be freshly regenerated to be able to dissolve and absorb sludge. The process can be performed on a de-energised transformer, but it is less efficient. the purification as an operation is limited only to moisture extraction, degassing and particulate filtration using high vacuum, heat and fine filtration. After circulating some 30,000 to 45,000 litres of oil, the clay beds are usually quite saturated and their efficiency drops sufficiently to justify reactvation. At this point the hot oil circulation continues to purify the oil. The clay is then reactivated in th column and the sludge contaminants, recovered as oily scum, are collected in a holding tank for waste disposal. After the reactivation phase, which lasts for about 16 hours, the processing can start again. The process will continue until the final oil sample drawn. from the main tank of the ransformer. indicates no acidity, high resistivity, low moisture and high breakdown voltage.

SAFETY MEASURES :

A system of alarms and interlocks is enforced during fully automatic operation as well as in manual override mode. The level of the oil in the transformer is monitored by a Wiscon Plant Supervisory System (WSS), which also shuts down the processor in case of possible hose rupture. Start up procedures are designed to avoid the introduction of air into the transformer.

OIL EVALUATION :

The physical and chemical properties of the oil before, during and after the MRU was shut down, one year after and two years after oil regeneration is determined by internationl standarsd methods. The results are shown in Table 1. During the process, daily oil samples were taken from the bottom main tank of the transformer and checked for acidity, moisture, breakdown voltage, resistivity and dissipation factor. The results indicated continuous improvements on the electrical, physical and chemical properties of the oil during the treatment.

No significant changes were observed in specific gravity, fire points, viscosity and flash point of the oil after processing. However, colour, acidity, moisture, interfacial tension. breakdown voltage, resistivity and dissipation factor improved considerably. Oils produced from different crude supplies are composed of different combinations of hydrocarbons. Some of these compounds act as gas absorbing agents in the oil and also as natural inhibitors to prevent oxidation. The proper balance of organic sulphur and aromatic content of the oil must not be reduce by the process . No alterations were observed to the organec sulphur and aromatic content of the processed oil. Oxidation stability tests were performed on the oil samples using IEC 1125 method C The results for acidity and sludgy content meet the requirement for IEC 296 specification limits. Inductively coupled plasma was used for measurement of metal particles and dissolved in oil. No detectable metals were observed in the processed oil. High dielectric poperties and interfacial tension of the processed oil indicates complete removal of dissolved polar or ionized contaminants.

ENVIRONMENTAL AND SAFETY :

The MRU contains clay in columns. The Permasorb process is the mechanism and control system that allows the clay in columns to be repeatedly reactivated. The Permasorb clay reactivation process is environmentally safe and clean. The clean oil trapped in the clay is recoverd and re-used again. The systems are equipped with triple oil spillage contingency for maximum environmental protection. Any oil leakage from various interface devices was monitored by level sensing devices and any initial small spillage was contained within the plant.

Tests	*Units*	*Before Process*	*After MRU Shut Down*	*One Year After*	*Two Yeare After*
Moisture	*mg/kg*	23	8	10	11
Acidity	*mg KOH/g*	0.20	< 0.01	0.01	0.2
Breakdown Voltage	*kV*	35	76	71	69
Sludge content	*% W/W*	0.02	< 0.01	< 0.01	< 0.01
Resistivity at 90°C	*MΩ*	2.5	226	184	160
Dissipation Factor at 90°C		0.095	0.005	0.006	0.009
Oxidation Stability					
Total Acidity	*mg KOH/g*	0.48	0.16	0.18	
Sludge	*% by Mass*	2.29	1.23	1.30	
Viscosity at 40°C	*est*	11.9	11.8	11.8	11.6
Interfacial Tension	*Dyne*	25	40	38	36
Aromatic Carbon	*% W/W*	10	10		
Paraffinic Carbon	*% W/W*	48	48		
Naphthenic Carbon	*% W/W*	42	42		
Aromatic Sulphur Content	*% W/W*	0.333	0.320	0.321	
Corrosive Sulphur		positive	negative	negative	negative
Phosphorous	*mg/kg*	11	ND	ND	ND
Zinc	*mg/kg*	3	ND	ND	ND

< Table 1: Results of Oil Analysis after Completion of Oil Reclamation and Two Years After. >

CONCLUSION :

The results of oil analysis during processing indicates a rapid reduction of moisture, acidity and other contaminants, together with an increase of breakdown voltage and resistivity. The physical and chemical properties of the oil after processing either improves or remains unchanged. The results from oil analysis, two years after the oil regeneration, indicate that the regeneration is effective in processsing oil withing the surface layer of paper insulation. The natural qualities of the oil, particalarly the natural antioxidant properties of the processed oil, remain unchanged. The sludge is removed, the oil and internal components of the transformer are cleaned of acids, chemical decomposition products, gases and moisture. The core and coil are never exposed to the environment and with this reclamation technique the life expectancy of the unit is increased and lost productivity is kept to a minimum.

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