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Transformer's History and its Insulating Oil

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ABSTRACT
The transformer is the most important components of the power system. In this paper history of transformer and its insulating material is highlighted.

1. INTRODUCTION

Transformer is generally considered to be one of the most important power system equipment. The insulation of transformer has been an integral part of the condition assessment for many decades. In power transformers, the paper-oil complex is the main component of the insulation, playing the triple role of dielectric barrier, mechanical support and heat escape route. The reliability of a power transformer is largely determined by its insulation condition. In this paper, an overview on the history of transformer and its insulating material is highlighted.

2.HISTORICAL BACKGROUND OF TRANSFORMER

The principle of electromagnetic induction had been discovered independently by Sir Michael Faraday on August 29, 1831, and by Joseph Henry. Faraday's device was a kind of primitive pulse transformer because he opened and closed a direct current, alternating current not being available at that time. It was, however, a 2-winding device wound on a closed core. At the Academy in Albany, New York, Henry drew a spark by interrupting a single coil. In 1836, C. J. Page, in Washington, D. C., produced the first autotransformer when he discovered that such sparks can be produced between any tapings of a coil if its circuit is interrupted at any point; the following year, N. J.Callan, an English priest, divided Page's coil into two parts without any galvanic connection between them. Interrupting the circuit of one coil, he produced sparks between the ends of the other. This 2-winding transformer was the logical end of the chain of experiments. All these devices worked with interrupted direct current and produced sparks only for experiments [1]. At the GANZ Factory in Budapest, the first closed core transformer was built on 16th September 1884 under the guidance of M. Dery, O.Blathy and K.Zipernovsky. The capacity of this transformer was 1400 Watt, frequency 40 Hz, voltage ratio 120/72 V, 11.6/19.4 ampere, ratio 1.67 to 1,single phase shell type transformer its core was made of iron wires. The GANZ inventors were the first to use the term "transformer" in their patent application, a name created from the Latin. M.O. Dolivo-Dobrowolsky, an engineer working with AEG in Germany, invented the three-phase transformer in 1890 and in the same year the first oil-cooled, oil–insulated transformer was constructed by Brown. The oil cellulose two-phase insulation system opened the way to higher capacities and voltage levels. At present, transformer designers are aiming at 2000 MVA capacity or more and units of 1500 kV voltage rating are now at the experimental operation.

3. INSULATING MATERIALS

There are three states of matter-solids, liquids, and gases and these states are characteristically best associated with particular types of electrical machines or applications. For instance, solid insulation development has been most influenced by rotating machines, liquid insulation by transformers and gaseous insulation by circuit breakers or switchgear.

4. TRANSFORMER INSULATING OIL

Petroleum based oils have been used as liquid dielectrics for transformers before 1887 [2]. These low viscosity paraffinic petroleum oils served the purpose of providing superior insulation when impregnated into paper or other solid dielectrics. They also provided an excellent heat transfer medium for removal of heat generated by electrical losses. Paraffinic crudes contain large quantities of paraffin wax and therefore have high pour points which make them unacceptable for use in electrical apparatus exposed to low temperatures. The oxidation of paraffin-based crudes produces an insoluble sludge, which increases the viscosity. It results in reduced heat transfer capabilities, overheating and reduced service life. As a result of this paraffin crudes were replaced with naphthenic oils. Although naphthenic oils are more readily oxidized than paraffinic but the oxidation products are soluble in the oil results in a reduction of problem [6]. Naphthenic oils contain aromatic compounds which remain fluid at comparatively low temperatures such as -40°C. The naphthenic crudes were also called as Coastal Crudes. One of the earliest concerns with mineral based insulating oil was its flammability.

Askarels comprise a group of synthetic fire resistant, chlorinated aromatic hydrocarbons used as electrical insulating liquids for applications where flammable mineral oils were not

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acceptable. The first transformer askarel was made in 1932 and it contained Aroclor (polychlorinated biphenyl, PCB's). The use of Aroclors as non-flammable insulating liquids continued until the mid 1970s when it was determined that they were no longer environmentally acceptable.

With the demise of the PCB's the industry turned to silicone fluids (polydimethyl siloxane or PDMS) [2, 8]. Silicones have excellent electrical insulating properties, higher fire point than mineral oils, less flammable fluids, excellent anti-oxidative properties and thermal stability due to their higher bonding energy of the Si-O siloxane bond which is the reason why the silicone oils have been adopted for the replacement of the PCB. At first stage, Kraft paper/silicone insulation was used for insulation and then it has changed to the aramid/silicone oil system. The aramid/silicone oil insulation systems have been used for more than 20 years, but not enough basic data were available to be used for insulation evaluation and diagnosis when compared to data for of the Kraft paper/mineral oil system [9]. A second commercial alternative to PCB fluids was the high molecular weight or so called high temperature hydrocarbons (HTH). Several of these high fire point hydrocarbon commercial fluids were available. They were good electrical insulating fluids, however, like silicones, they also were flammable but with high fire points [2].

Transformers filled with synthetic liquids such as silicone, ester, perchloroethylene, etc. are used in special applications today. These liquids have some different characteristics from those of transformer oils, and normally cannot be used as direct replacements for mineral oil in service or for repaired units. They have good dielectric and heat transfer properties but their relatively high cost and availability has limited their use to special transformer applications [10].

Members of the chlorofluorocarbon family (Freons) were used commercially as electrical insulating fluids. These materials are non-flammable, have very good electrical insulation characteristics, but are expensive. The boiling point ranges are quite low and thus they vaporize at normal transformer operating temperatures. This has provided an opportunity to produce electrical equipment using two phases cooling which is a very effective heat removal process [4].

Tetrachloroethylene (C2Cl4) is a non-flammable insulating fluid that was introduced commercially in 1980 under the tradename "WECOSOL" [5]. It has good electrical properties and is a low viscosity fluid that provides excellent heat transfer. It can be used alone or it mixes well with mineral transformer oil to remain non-flammable and provide improved lubricating properties at lower cost [8].

Isopropyl biphenyl is a hydrocarbon fluid composed of propylated biphenyl isomers which is used as a capacitor dielectric fluid. It was introduced under the tradename WEMCOL as a replacement for polychlorinated biphenyls (PCB's) in 1978 [6]. It is neither non-flammable nor "less flammable," but it has excellent properties for a capacitor insulating liquid.

Crude oil selection is the most important step in the manufacturing of insulating oil. The degree of refining of the crude and kind of process and treatment may greatly change the constituents in the final product. In the refining process the most desirable characteristics of the crude oil are selected and the less desirable constituents removed. The end product is a structure with the desired proportions of aromatic rings, naphthenics and paraffins. The process may include hydro treating/hydrogenation, solvent extraction, dewaxing, acid and clay treatment. However, there is no single best method for the manufacture of good insulating liquid. Regardless of the refining method used the insulating oil produced should have high electrical performance, gas absorbing properties, chemical stability and resistance to oxidation. Additionally, optimum aromatic hydrocarbon concentration and sulphur and nitrogen content are important factors.

4.1. CHARACTERISTICS OF INSULATING OIL

The reliable performance of mineral insulating oil in an insulation system depends upon certain basic oil characteristics, which can affect the overall performance of the electrical equipment:

- High electric strength
- Low viscosity so that its ability to circulate and transfer heat is not impaired
- Proper oxidation resistance to ensure long life in service
- Good resistance to emulsion to prevent holding water in suspension in it
- Free from inorganic acid, alkali and corrosive sulphur which causes corrosion of metal parts and insulation and accelerate the production of sludge.
- Free from sludging under normal separating conditions
- High flash/fire points
- Low pour point
- Low water content
- Good electric and thermal properties
- Chemical and thermal stability
- Low flammability
- Environmental acceptability
- Low cost

4.2. OIL ANALYSIS

Transformer oil is poorly biodegradable; it could contaminate our soil and waterways. Petroleum products are eventually going to run out, and there could be serious shortages even by the mid-twenty-first century. So we should seriously think of alternate natural sources of insulating fluids. Due to the utility interest in biodegradable insulating fluids, research efforts were started in the mid 1990s to develop a fully biodegradable insulating fluid. Vegetable oil [11, 12, 13] was considered the most likely candidate for a fully biodegradable insulating fluid. Vegetable oil is a natural resource available in plenty; it is a fairly good insulator, and is fully biodegradable. The researchers soon recognized that vegetable oils needed further improvement to be used as a transformer fluid. The fluid in a sealed transformer remains in the unit for many years (as many as 30 to 40 years, unless the oil is changed in between). Only in the larger units is the fluid periodically

refreshed. Long-term stability is of critical importance. Vegetable oils inherently have components that degrade in a relatively short time. The degree of unsaturation is an indicator of thermal instability, becoming more unstable as the degree of unsaturation progresses from mono- to triunsaturation.

The relative instability to oxidation is roughly 1:10:100:200 for saturated, mono-, di-, and tri unsaturated C-18 triglycerides [15]. In transformers, the presence of copper enhances tendency for oxidation. Powerful oxidation inhibitors are needed for the oils used in transformers. Another factor is the purity of the oil. The oil has to be free of conducting ionic impurities to acceptable levels, and commercial grade oils are not of this purity.

Only recently have transformer-grade vegetable oils become available. The first commercial product was BIOTEMP®, patented in the U.S. in September 1999 by ABB. The base fluid was high oleic oil (such as sunflower oil, Canola oil upgraded to this level of oleic content has also been tested for use. The commercially available RBD grade is the starting material, where RBD stands for Refined, Bleached, and Deodorized etc) with over 80 percent oleic content. The BIOTEMP® is now used in some distribution and network transformers in critical areas. Another U.S. patent was issued later, in September 1999, for transformer oil from regular soybean oil, obtained by Waverly Light & Power in Iowa, though this product is not yet commercially used. It is not high oleic oil. In March 2000, another U.S. patent was granted to Cooper

Industries in Milwaukee, WI under the trademark Envirotemp FR3®. This fluid also is from standard-grade oleic base oils, and is used commercially in some distribution transformers. A second patent was issued to the ABB inventors on the BIOTEMP® fluid in August 2001 [14].

Vegetable oils are hygroscopic; hence, they may absorb water at as much as 1200 ppm or more, at saturation and at room temperature. It is desirable to lower this to 100 ppm. To stabilize the oil, it is necessary to add suitable antioxidants. Commonly used inhibitors such as 2, 6-di-tert-butyl-paracresol (DBPC) and food-grade antioxidants are not powerful enough to produce oil that will pass the ASTM oxidation tests, such as D-2440 and D-2112.Aspecial antioxidant package that uses complex phenols and amines is used in the BIOTEMP® fluid. The FR3 fluid does not pass the ASTM oxidation test because of its lower mono unsaturated content, even with reasonable amount of inhibitors. The oxidation stability of vegetable oils is greatly dependent on the mono unsaturated content, which should be over 80% for long-term transformer use [16].

C. Perrier et al., investigated mixtures consisting of mineral oil and two other kinds of insulating liquids (namely silicon and synthetic ester oils). These three liquids are analyzed and compared on the basis of heat transfer, BDV, aging stability and electrostatic charging tendency (ECT). Different mixtures were considered. However, the emphasis has been put on the mixtures based on 80% of mineral oil with 20% of another fluid. This proportion appears to be the best compromise from a technical and economical point of view.

David P. Stockton [19] represents the natural ester transformer fluids its history, properties and compared with the conventional mineral oil fluid.

CONCLUSION

The basic of transformer is electromagnetic induction which was discovered in 1831 by Sir Michael Faraday. From 1831 to till date there is great development in the design, capacity etc of the power transformer. Different insulating oil and its combinations were developed and tried time to time, but the most successful is naphthenic oil because of its cost and availability.

REFERENCES

[1] A.A. Halacsy and G.H. Von Fuchs, "Transformer Invented 75 Years Ago", Power Apparatus and Systems, Part III. Transactions of the American Institute of Electrical Engineers, April 1961, vol. 80, Issue 3, pp: 121-125.

[2] H.R. Sheppard, "Century of Progress in Electrical Insulation 1886- 1986" IEEE Electrical Insulation Magazine, Sept. 1986, vol. 2, Issue: 5, pp: 20-30.

[3] Lee, and K. Neville, "Handbook of Epoxy Resins", McGraw Hill Book Company, 1967.

[4] H. M. Schneider, R. E. Gearhart and E. T. Norton, "Dielectric strength of C2Cl3F3 in two-phase mixtures, Fourth International Symposium On High Voltage Engineering, Athens, Greece, Sept. 1983.

[5] K. R. Linsley, "Nonflammable small power transformers," American
Power Conference, April 29, 1981.

[6] G. Mercier, "WEMCOL capacitor fluid development,"
Electrical/Electronics Insulation Conference, Chicago, 1977.

[7] C.C. Claiborne and H.A. Pearce, H.A, "Transformer fluids", IEEE
Electrical Insulation Magazine, vol. 5, Issue 4, July-Aug. 1989, pp. 16–19.

[8] I. Fofana, V. Wasserberg, H. Borsi and E. Gockenbach, "Challenge of
mixed insulating liquids for use in high-voltagetransformers.1. Investigation of mixed liquids", IEEE Electrical Insulation Magazine,
May/Jun 2002, vol 18, Issue: 3, pp: 18-31.

[9] T.V. Oommen, C.C. Claiborne and J.T. Mullen, " "Biodegradable
electrical insulation fluids", Electrical Insulation Conference, 1997, and Electrical Manufacturing & Coil Winding Conference, 22-25 Sept.
1997, pp 465 – 468.

[10] P. Boss and T.V. Oommen, "New insulating fluids for transformers based on biodegradable high oleic vegetable oil and ester fluid", IEE
Colloquium on Insulating Liquids (Ref. No. 1999/119), 27 May 1999, pp.7/1 – 7/10.

[11] C.C. Claiborne, E.J. Walsh and T.V. Oommen, "An agriculturally based

biodegradable dielectric fluid", IEEE Transmission and Distribution Conference, vol. 2, 11-16 April 1999, pp. 876 – 881.
[12] T.V. Oommen, "Vegetable oils for liquid-filled transformers" IEEE Electrical Insulation Magazine, vol.18, Issue 1, Jan.-Feb. 2002, pp. 6–11.
[13] S.S. Lin, "Introduction to fats and oils technology," AOCS Publication, pp. 211-231, 1997.
[14] Y. Bertrand and L.C. Hoang, "Vegetal oils as substitute for mineral oils", 7th International Conference on Properties and Applications of
Dielectric Materials, vol. 2, 1-5 June 2003, pp. 491 – 494.