COMPARATIVE ANALYSIS OF FRESH AND USED POWER TRANSFORMER OILS

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ABSTRACT

Uninterrupted electricity supply is a vital issue for Nigeria today. This is because the reliability for power transformer to generate electricity to be used for industrial activities, electric utility companies and our homes has become far more important to our present generation for financial reasons. This work presents experimental research on the variations of the physicochemical properties and composition of two transformer oils of different levels of degradation. The first one is a virgin/fresh new oil while the second was collected from an operating transformer after being used for five (5) years (used transformer oil). The physicochemical characteristics of both samples were studied using American Society for Testing Material (ASTM) standard test, and were found to be within the specified range by ASTM standard. Results for physicochemical characterization of both samples A and B gives acid value of 0.045 ± 0.089 & 0.12 ±0.07 (mg KOH^{-1}), density of 0.75 ±0.01 & 0.99 ± 0.01 (g cm^{-1}), and Flash Point of 143 and 152 (^{o}C) values respectively. However, the used oil sample presents physicochemical properties of narrow value to standard specifications which indicated its high level of degradation in contrast to the fresh oil sample. The FTIR results of the two samples were compared and it revealed that they have similar compounds of paraffins, naphthene and aromatics present in them. Although the used oil indicated the presence of phenols, which is indicative of oxidation process occurring in the oil.

Keywords: *Fresh transformer oil, used transformer oil, insulation, FT-IR*

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INTRODUCTION

The oil used in the insulation system of power transformer require adequate monitoring to extend the lifetime of the transformer, while maintaining system reliability (Electrical4U, 2019). This is because the reliability of the insulation system in a transformer is a key factor for the reliability of operation of the transformer (Schneider *et al*., 2005). Just as people go for medical checkup to know their health status as a precaution against unexpected breakdown, inadequate monitoring of the power transformers insulation often result in sudden breakdown of the power equipment.

Transformer oil, also known as insulating oil is an oil derived by refining and further processing of petroleum or vegetable oil (Darwin & Follist, 2007; Abdelghaffar, 2012; Muhamad & Razali, 2016). It has an excellent electrical insulating properties and tends to resist to changes in its properties at high temperatures (Muhamad & Razali, 2016). It serves primarily as an electrical insulator in power transformer, besides other functions such as dissipating the heat of the transformer, preventing luminous current discharge and also preventing oxidation of the cellulose insulation (Hembrom, 2013).

This oil being used for electrical insulation in power transformers degrades over time due to the influence of various factors, and when left untraced may lead to deterioration and consequently malfunctioning of the equipment. Yuzhen *et al*. (2017) reported that majority of operating transformers worldwide are close or above their stipulated lifespan; and statistical report shows that the normal monitoring duration of the power equipment, which malfunctions as a result of insulation issue, is 17.8 years (Nynas, 2004). This is half of their designed lifespan of 35 to 40 years. Also, about 75 % of transformer malfunctioning usually results from insulation issues (Yuzhen *et al*., 2017). This could largely be attributed to the increase in the level of system voltage with new developments, thereby resulting in a subsequent increase in pressure on the insulation material (Hembrom, 2013; Yuzhen *et al*., 2017).

In Nigeria, the "corrective maintenance strategy" is adopted for power transformers where it is used till it breaks down before decision will be made whether the equipment should be repaired or replaced. This put the electricity end users in blackout pending when the issue is resolved. This strategy appears to have the lowest cost of maintenance, but the damage caused by the failure could result to higher cost compared to a more appropriate maintenance system (Schneider *et al*., 2005; EL-Sayed *et al.*, 2009).

This work is aimed at estimating the level of degradation of power transformer oil used for an operating transformer with respect to its usage duration and to make available a guideline data for transformer oil service life.

MATERIALS AND METHODS

Sample Collection

Samples of mineral-based transformer oil samples, comprising of fresh (virgin/unused) and used oils were sourced from Abuja Electrical Distribution Company (AEDC), Nigeria. Prior to the collection, the sample containers were washed with distilled water, dried and rinsed three times with the respective samples. The used oil was collected from the bottom of an installed distribution transformer in accordance with ASTM D923 sampling method. The samples were collected in sufficient quantities for replicate analysis and stored under normal condition until required for analysis.

Methodology

The following are experimental test methods carried out based on the American Standard for Testing and Material (ASTM) method.

Visual Examination

Visual examination was carried out in accordance with ASTM D1524 test method. A beam of light was passed through the sample to determine transparency and identify foreign matters.

Determination of Acid Value

Determination of acid value was done in accordance with ASTM D923 test method. The test was carried out at IBBUL Chemistry laboratory. 50 cm^3 of neutral ethanol was measured into a 250 cm^3 conical flask and 5g of the oil sample was dissolved in it. few drops of phenolphthalein indicator were then added to the solution and it was titrated with standard KOH (0.1 M) to a faint pink colour. The procedure was carried out in triplicate, and calculations for the mean and standard deviation was done on the values obtained. **Figure 1** shows the set up for acid value test at Chemistry Laboratory, IBBUL.

$$\text{Acid value (in mg)} = \frac{56.1 \times N \times T \times 100}{1000 \times G}$$

Where:
N = Normality of standard KOH used (0.1 M)
T = Average Titration volume
G = weight of sample (5 g)

56.1= molar mass of the titrant (KOH)

Density Test

Density test was carried out in accordance with ASTM D1298 test method. 50 mL of the oil sample was transferred into the measuring cylinder. A hydrometer was introduced into the measuring cylinder containing the fresh transformer oil and left to settle for 2 minutes before the readings was recorded. The procedure was carried out in triplicate, and calculations for the mean and standard deviation was done on the values obtained. **Figure 2** shows the setup for density test carried out at the quality control laboratory, NNPC/NPSC depot, Minna.

Flash Point

Measurement of flash point of the oil samples was done in accordance with ASTM D92 test method. A Pensky-Martin closed cup Flash Point apparatus was used. The oil sample was transferred to the test cup up to the prescribed level, and then refluxed with slow and constant stirring rate. At every 10 ^oC temperature increase, flame was introduced for some moment using a shutter. The temperature in which a flash was observed in the form of sound and light was recorded as the flash point. The temperature was measured using a thermometer and the procedure was repeated for three times, then calculations for the mean and standard deviation was done on the values obtained. **Figure 3** shows the setup for flashpoint testing carried out at the quality control laboratory, NNPC/NPSC depot, Minna.

Fourier Transform Infrared Spectroscopy

The FT-IR analysis was carried out with FT-IR spectrometer. Scanning of the samples was done with infrared radiation via frequency of 4000-650 cm^{-1} to get the spectrum. The quantity of absorbed radiation by the sample was plotted as a function of the wave number of the radiation absorbed by a detector. Every absorption bands observed from the IR spectrum indicates energy absorption. The functional groups of the samples were identified from the spectra.

RESULTS AND DISCUSSION

Physicochemical Properties

The values obtained for the physicochemical properties (visual examination, acid number, density and flashpoint), with the standard deviations of each property of both oil samples with their corresponding ASTM standard values are presented in table 1.

Table 1: Results of Physicochemical properties and their ASTM standards.

Parameters	**Fresh transformer oil**	**Used transformer oil**	**ASTM**
Visual aspect	Clear/transparent	Opaque	Clear/transparent
Acid number (Mg KOH^{-1})	0.045 ± 0.089	0.12 ± 0.07	0.20
Density (g cm^{-3})	0.75 ± 0.01	0.81 ±0.01	0.55-0.89
Flashpoint (^{0}C)	143	152	140-155

FT-IR Results

The FT-IR spectra and the vibrational modes for the oil samples is shown in Figure 1 and Table 2.

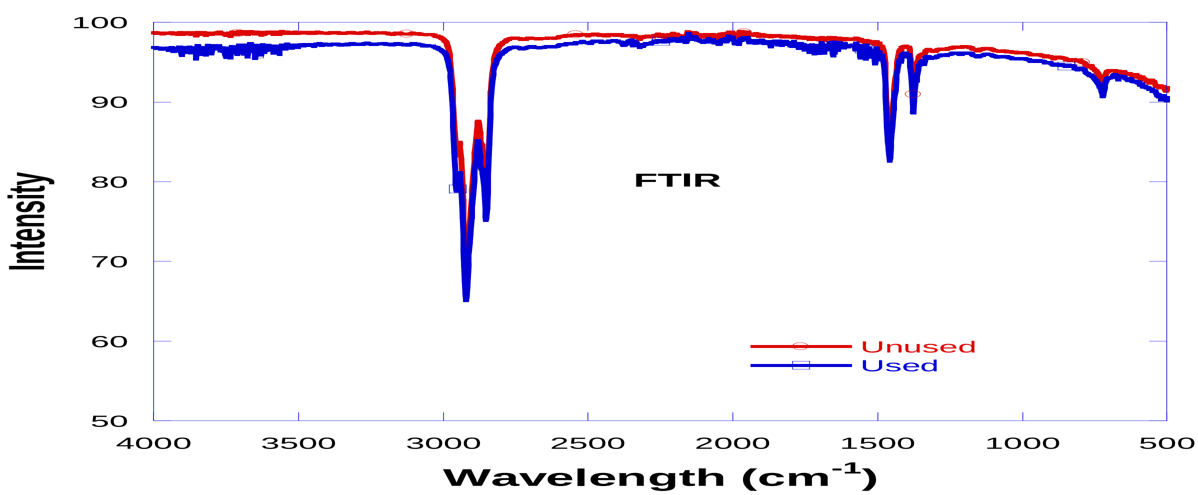

Figure 1: FT-IR Spectra

Table 2: FT-IR spectra and Vibration Mode for the Oil Samples

Frequency (cm^{-1})	Vibration Mode	Relative intensity	Compound present
3000 – 2500	C-H symmetric/asymmetric stretching	Very strong	Alkane
1500-1300	C-H scissoring vibration of CH_2 and CH_3	Medium	Alkane
4000-3500	O-H stretch	Weak	Phenol

Visual Examination

The oil's visual characteristics is very important for oil analysis. Both samples are homogeneous with no emulsion observed. However, fresh transformer oil was clear and transparent, in contrast to used transformer oil which is being used, and presents an opaque vision with a dark color; it indicates the presence of impurities originating from the transformer parts (Tanteh *et al.*, 2014).

Density

The density of the two oil samples varies weakly from the fact that the oils are of the same nature with varying level of degradation. **Table 1** presents the density variations, in which the densities of the fresh and used oils are relatively closer to each other and presents densities lower than the maximum specified limit by ASTM. The density for used transformer oil was greater than that of fresh transformer oil. This could be due to the presence of water and foreign particles in used transformer oil.

Acid Number

The acid number for both samples was calculated in mg KOH^{-1} according to the established formula. **Table 1** presents the variations of acidity of samples with respect to the ASTM value. The measured values are below the limits fixed by ASTM standards. Higher value was recorded in used transformer oil could possibly be due to the effect of wearing of the components of the transformer. The increase in acidity of the oil sample indicated the beginning of oxidization in it. This was attributed to acid by-products, which are usually charge carriers. Their presence will cause a decrease in the dielectric property of the oil and increase in its solubility with water, which can, in turns lead to degradation of the paper (cellulose) insulation.

Flash Point

The flash point for both samples varies from 143 to 152 °C and used transformer oil had a higher value than fresh transformer oil. However, both samples were within the acceptable flash point range of the specified limit by ASTM. The phenomenon in case of used transformer oil which was used and presents an elevated rate of impurities may result from the increase in temperature and degradation of the oil. Long-term usage of the oil at elevated temperature under malfunctioning conditions may yield enough quantity of lower molecular mass hydrocarbons which are highly volatile and causes a decrease in flash point value. Hence, the lowering in flash point values indicated the presence of volatile and combustible components in the oil.

FT-IR Analysis

The results of the FT-IR analysis are shown in **Figure 1.** The frequency, mode of vibration, relative intensity and compounds present were shown in table 2 for both the fresh and used oils. The samples give strong absorbance peaks at 3000 -2500 cm^{-1} which indicates C–H stretching. The peak at 1500-1300 cm^{-1}represents C–H scissoring of CH_2 and CH_3 groups. These are the evidences for the presence of alkanes in both samples (Prasad *et al.*, 2018). However, the weak absorbance peaks at 400-3500 cm^{-1} observed in the used oil sample indicated the presence of O–H group, this is evident that oxidative degradation have been initiated in the oil, but still have the potential to be used for insulation activity in the transformer (Anton *et al*., 2008).

CONCLUSION

Degradation of transformer oil can occur at a slow pace under normal conditions of transformer operation. However, the phenomena tend to accelerate detrimentally because of electrical and thermal faults. The oil proceeds to chemical changes which results in production of soluble gases and new functional groups of hydrocarbon composition. From our experimental results, it is evident that some physicochemical properties such as flash point and density of the oil are insignificantly varied for long time usage, consequently its range in the specified limit for long period, so these may not be regarded as good criterions to entail the oil degradation resulting from ageing. However, the total acidity rises slowly with long time usage, and affects one of the most important properties of the oil (dielectric breakdown voltage). Hence, acidity may be considered as one of the main agents for oil degradation. Therefore, the chemical tests especially for acidity is very important for transformer oil monitoring.

REFERENCES

Abdelghaffar, A. A. (2012). The feasibility of using a vegetable oil-based fluid as electrical insulating oil. University of Leicester.

Anton G., Ilyana, K., Liliana, T. (2008). Determination of oxidation products in transformer oils using FT-IR spectroscopy. Journal of Molecular Structure 872, pg. 18–23.

Darwin, A. and Follist, C. P. (2007). The use of natural ester fluids in transformers. Mat past Avera T and N, UK.

Electrical4U. (2019). Transformer Oil: Testing, Types & Properties. https://www.electrical4u.com/transformer-insulating-oil-and-types-of-transformer-oil/?sa=X&ved=2ahUKEwifz5XMroLiAhXGKVAKHahUAXkQ9QEwAHoECAsQAg. Accessed May 4, 2019.

EL-Sayed, M. M., EL-Refaie, Mohamed, R., Salem, and Wael A., Ahmed (2009). Prediction of the Characteristics of Transformer Oil under Different Operation Conditions. World Academy of Science, Engineering and Technology

Hembrom, S. (2013). Analysis of aged insulating oil for early detection of incipient fault inside the high voltage equipment. Department of Electrical Engineering. National Institute of Technology, Rourkela. Rourkela-769008, India. http//:www.nitrkl.ac.in.

Muhamad, N. A. and Razali, S. H. M. (2016). Electrical and Chemical Properties of New Insulating Oil for Transformer Using Pure Coconut Oil. Journal of Advanced Research in Materials Science ISSN (online): 2289-7992 | Vol. 25, No.1. Pages 1-9, 2016.

Nynas, (2004). Transformer Oil Handbook. Nynas Naphthenics publication, first edition, Sweden.

Prasad, A. K., Kumar, R. and Mishra, M. K. (2018). FTIR spectroscopy Investigation of waste transformer oil as an alternative fuel for CI Engine. International Journal of Advanced Scientific Research and Management, Vol. 3 Issue 9, ISSN 2455-6378195. www.ijasrm.com.

Schneider, J. *et al. (*2005). Asset Management Techniques, 15th PSCC, Liege.

Tanteh, D. N., Al-liddawi, S. Y., Ssekasiko, D. (2014). Properties of transformer oil that affect efficiency. School of Engineering, Department of Electrical Engineering, Blekinge Institute of Technology, S-371 79 Karlskrona.

Yuzhen, Lv, Muhammad Rafiq, Chengrong Li and Bingliang Shan (2017). Study of Dielectric Breakdown Performance of Transformer Oil Based Magnetic Nanofluids. (https://www.mdpi.com/1996-1073/10/7/1025/htm). Accessed April 13, 2019.