Analysis and Diagnostic of Distribution Transformer Oil in Lieu of Life Expectancy

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Abstract:
All over the worldmineral oil immersed transformers play an important role in generation and transmission of electric power. Mineral based insulation oil is used for liquid insulations in transformers for the past some decades. During their service life thermal, mechanical and electrical faults usually occur in transformer due to local overheating, hot spot, leakage flux, arcing, eddy current etc. These faults largely affect the liquid insulation resulting in production of unique degraded products that are present in transformer oil permanently or for a considerably short period. Presence of these products in the oil changes its basic property and increases the aging process of transformer oil.This paper presents the experimental results of effect of aging of transformer and analysis the change in characteristics such as density, viscosity, dielectric strength or breakdown voltage, flash point and fire point of the mineral based transformer oil with aging and X-Rayfluorescence(XRF) test is carried out for analysis of presence of corrosive sulphur in pure and used oils. The presence of corrosive sulphur in the oilaffect the copper windings and may form copper sulphide which deposits on oil-paper insulation system which can lead to insulation failures in power transformers.
***Keywords**: viscosity;breakdown voltage; flash point; fire point;XRF; mineral oil*

1. INTRODUCTION:

Transformers are considered as essential components in electrical power generation, transmission and distribution system [1].In industries like power production units, aluminium and steel industries, fertilizer and chemical industries etc. transformers are considered as important machinery. The insulations utilized in transformer are classified into solid, and liquid. Liquid dielectrics are used in most of the transformers as an insulating material [2]. The mineral oils produced from crude petroleum by

fractional distillation and subsequent treatment has been utilized as the liquid insulation and heat dissipation for over 75 years [3-4]. Other than a transformer mineral oils are also used in different electrical devices like different types capacitors that store charge and energy for use in high voltage application, [5] switches, circuit breakers,etc. Mineral oils are widely used in transformers as an

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insulating agent and coolant because these oils are easily available in large quantities at low cost. The internal state of transformer gets degraded as a result of its subjection to thermal, mechanical, electrical and chemical stresses during their function [6]. The lifetime of a transformer mainly controlled by the condition of the oil-paper insulation system, which is auniversally accepted fact [7-8]. The main properties of transformer oil are categorised into the physical, chemical and electrical property. Some of the significant properties of the transformer oil are density, viscosity, dielectric strength or breakdown voltage (BDV), flash point, fire point and corrosive sulphur content. Insulation capacity of transformer oil is related to its electrical properties and heat transferability capacity is associated with its physical properties. The mineral based transformer oil is composed of both hydrocarbons and non-hydrocarbons [9]. Hydrocarbon which consist of carbon and hydrogen only, constitutes the main part in transformer oil whereas non-hydrocarbon presents in small quantity. Generally mineral based insulating oil is classified into two types [10] such as Paraffinic oil and Naphthenic oil. In this paper transformers are filled with naphtha based mineral insulating oil. During the service time of transformer, transformer oils are exposed to electrical, mechanical and chemical stresses. Due to the jointed or distinct action of these stresses, aging phenomenon of transformer oil initiated which leads to slow and permanent changes in their properties. As effect of the aging process transformer oil loses its strengthslowly and start to decomposed and oxidized and ultimately starts to create mud. And this referred to the degradation phenomenon of the transformer oil.The keyaspects that increases transformer oil aging and degradation phenomenon are moisture, oxygen and other contaminants.And the presence of corrosive Sulphurin transformer oil also disturb the insulating characteristic of the oil-paper insulation. The value of characteristic properties of transformer insulation oil are changed day byday as per aging of the transformer.In the present paper we showed it in pictorial way that how all parameters influenceaging of transformer in graphical measures and make comparison between them.

2.MATERIALS:

In order to investigate and compare different characteristics property of pure and used mineral insulating oil, oil samples were collected fromGramtarang transformers laboratory, Centurion University of Technology and Management, Odisha. First oil sample was collected after filtration. The filtration of the oil was carried out at a temperature about 333Kand this process removes dissolved moisture unwanted dust particles, sludge and dissolved gases from the oil. Second sample was collected from transformer which in service for one year. third sample was collected from transformer which in service for 2 year. All the oil samples are collected from lower level of the tank.

3. EXPERIMENTAL DETAILS:

3.1 Measurement of density

Density of liquid depends on its chemical composition. The density of transformer oil is elementary physical property of the oil. Density of the oil is estimated by using Pycnometer at 303K, 313K, 323K, 333K.

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The Pycnometer setup is shown in fig.1. The densities of the transformer oil were estimated using a 25 ml Pycnometer bottle. The Pycnometer bottle with the oil was submerged in a temperature-controlled water bath. The density was estimated using the equation

$$\rho_2 = \frac{w_2}{w_1}\rho_1 \text{---------------------------------} (1)$$

Where, w_1 = weight of distilled water, w_2 = Weight of transformer oil, ρ_1 = Density of water, ρ_2 = Density of transformer oil.

Fig.1. Density measurement by Pycnometer

3.2 Measurement of viscosity

Viscosity of the oil is a measure of its resistance to flow in normal condition without any external forces. It defines the internal friction of the moving oil. The shear resistance given by the transformer oil for the flow is measured by measuring the viscosity [11]. The oil flow appearances are indirectly being a part of the heat transfer capability of transformer oil. The oil used in transformers should have great mobility so that it is successfully transfer heat produced at winding and core through the transformer's radiator. It is desired to use oil in the transformer with low viscosity as it shows fewer resistance to the conventional movement of oil thus not disturb the cooling of the transformer. With decrease in operating temperature viscosity of oil increases. But the rate of increase of viscosity varies from one oil to other. The transformer oil with low viscosity is vitaland it is similarly essential that the rate of increase of viscosity is as low as possiblein accordanceto reduction in temperature. The viscosity measurement of pure and used transformer oil samples is conducted by using the Ostwald's Viscometer set-up at 303K, 313K, 323K, 333K. The flow time of oil sample has been measured for calculating viscosity of the oil sample. The Ostwald's Viscometer set-up is presented in fig.2. The viscosities of the transformer oil were estimated using Ostwald's viscometer standardized with distilled water. The Ostwald's viscometer with the transformer oil was submerged in a temperature-governed water shower. The time of flow was estimated by using an advanced stopwatch with anaccuracy of 0.01 s. The viscosity was calculated using the equation,

$$\eta_2 = \eta_1 \left(\frac{t_2}{t_1}\right)\left(\frac{\rho_2}{\rho_1}\right)\text{---------------------------------} (2)$$

Where, η_1 = Viscosity of distilled water, η_2 = Viscosity of transformer oil, ρ_1 = Density of distilled water, ρ_2 = Density of transformer oil. t_1 = Time of flow of water, t_2 = Time of flow of transformer oil.

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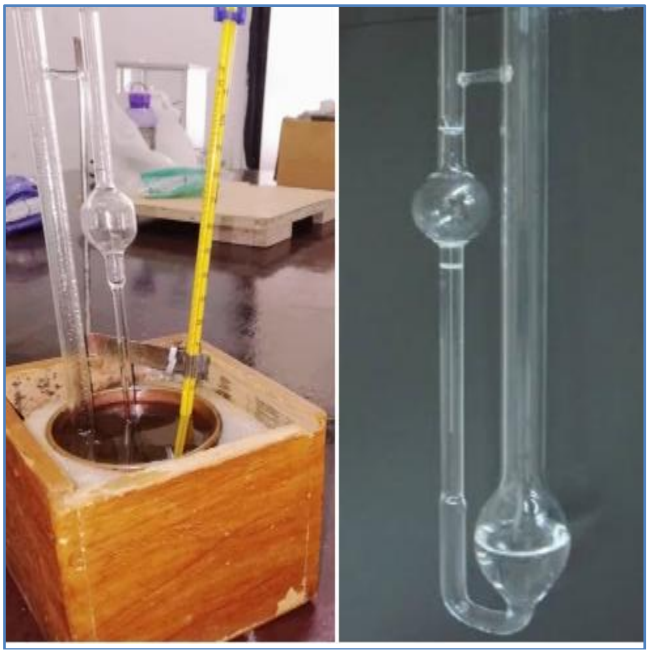
Fig.2. Viscosity measurement by Ostwald's viscometer

3.3 Measurement ofbreakdown voltage

The capability of a faultless insulating medium is refereed by measuring the dielectric strength of that medium. And breakdown voltage test is carried out to examine the dielectric strength of Transformer oil. Breakdown voltage (BDV) is the voltage in KV at which electric sparkstarts between two spherical electrodes (in some cases the electrodes are cylindrical) immerged in the oil with a specific gap of 2.5mm (in some cases the gap is 4mm). Dielectric strength or breakdown voltage is the ability of transformer oil to bear electric stress with no failure. The BDV of transformer oil is based on the purity of the oil. Low value of BDV point out the existence of contaminants such as moisture, dust or other conductive particles in the oil [11]. The breakdown voltage of insulating oil is calculatedby using BDV measurement kit in accordance to the standard IEC 60156 [12].The minimum value of breakdown voltage at which the transformer oil can safely usein the transformer is measured as 30KV. Fig.3. shows the breakdown voltage measurement setup. The dielectric strength of the transformer oil is calculated by using the formula,

$$dielectric\ strength\ of\ the\ oil = \frac{breakdown\ \ voltage\ \ of\ the\ oil}{gap\ between\ \ the\ electrodes\ \ (2.5mm)} \text{-----------------(3)}$$

The transformer oil with high BDV may not be completely free from any contamination. This is because the quantity of impuritiesexistamong the electrodes is not sufficiently high enough to disturb the average breakdown voltage of the oil. It is testified that uncaring sampling and testing procedure of oil has been the basis of 99% of wrong dielectric values [13]. The breakdown voltage measurement should be done carefully in order to avoid immature failure in transformer.

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Fig.3. Breakdown voltage oil kit

3.4 Measurement of Flash point and fire point

The fire safety features of transformer oil are examined by measuring the flash point and fire point of the oil [11]. The lowermost temperature at which transformer oil provides adequate quantity of gaseous component to procedure an ignitable mixture in air, is called as its flash point. When ignitable mixture is subjected to a flam under specified condition this mixture provides a momentary flash. And fire point is the lowest temperature at which transformer oil provides adequate quantity of gaseous component to yield a mixture in air that burn continuously for at least 5 seconds, when a flame is brought near it. The Flash point and fire pointof transformer oil are thus considered as its important characteristicas it presents thepossibility of fire danger in the transformer. Hence it is preferred to use the oil with very high flash point in transformer. Flash point test specifies the flammability of the transformer oil. Generally Flash point of transformer oil is more than 413K. As per the standard ASTM D93, the measurement of flash point and fire point of transformer oil is done by using Pensky-Martens closed cup apparatus [14]. The flash point and fire point measurement setup is shown in fig.4.

Fig.4. Pensky-Martens closed cup apparatus

3.5 Corrosive sulphur content:

Sulphur elements are very corrosive to metal surfaces and should not be exist in transformer oil to be used. The existence of sulphur in oil can lead to corrosion ofcopper windings and on reaction with copper form copper sulphide which deposits on surface of paper insulation in transformer and damage it. Sulphur in transformer oilcan either arise from the crude oil from which the transformer oil is derived or from the rubber houses that are utilized during oil processing or from gasket materials. In order to detect corrosive sulphur in pure and used oil samples, X-ray fluorescence (XRF) technique is used. Fig.6. shows the XRF device setup.

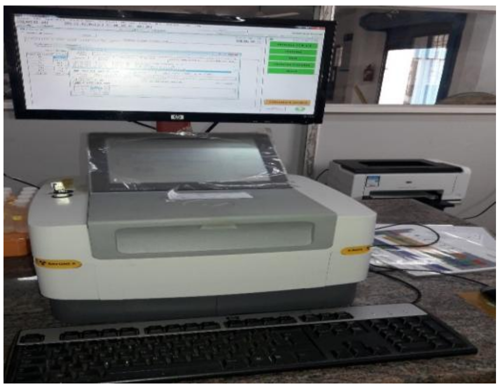

Fig.5. X-ray fluorescence (XRF) set-up.

4.RESULTS AND DISCUSSIONs:

The parameters such as density, viscosity, breakdown voltage, flash point, fire point and conductivity of pure and used mineral insulating oil samples measured by using procedure given in the methodology section to make a comparison.

And presence of corrosive sulphurwhich have a greater influence on insulating property of transformer oil are analysed by usingX-ray fluorescencetechnique. The density of oil samples is given in Table 1 and variation of oil samples with density is represented in fig.6.and variation between density and temperature is shown in fig.7.

The viscosity of the oil samples is listed in Table 2 and variation of viscosity with oil samples is shown in Fig.8 and variation between viscosity and temperature is shown in fig.9. The breakdown voltage of oil samples is listed in the Table 3 and the comparison of breakdown voltage with oil samples is denoted in Fig.10. The fire safety parameters of oil samples such as flash point and fire point are listed in the Table 4 and the comparison of flash point and fire point with oil samples is denoted in Fig.11 and Fig.12 respectively. And the result of X-ray fluorescence of oil samples is given in table-13,14 and 15.

Table-1: Values of density of oilsamples in kg/m$^{3.}$

Temperature(K)	pure oil	used oil (1year)	used oil (2 year)
303 K	828.76	831.43	833.67
313 K	822.73	825.12	828.03
323 K	817.53	819.78	821.62
,323 K	814.03	815.77	818.37

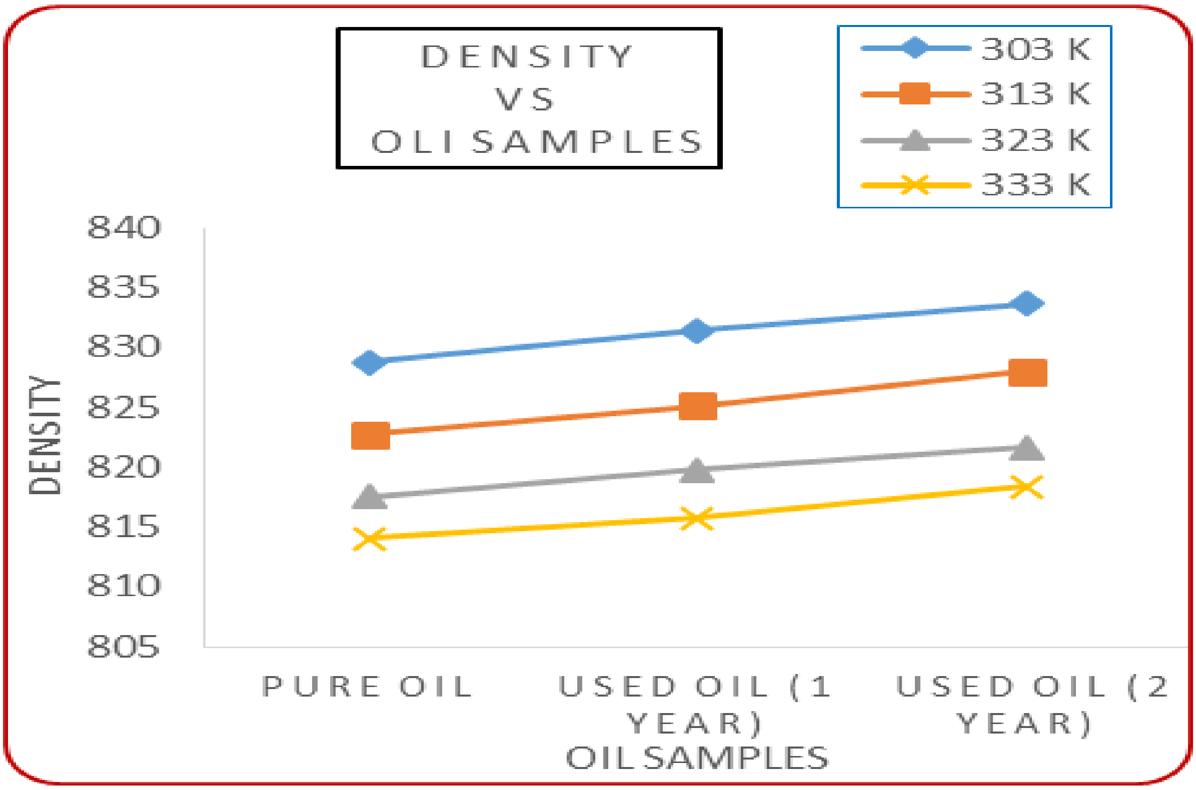

Fig-6variation of density with oil samples

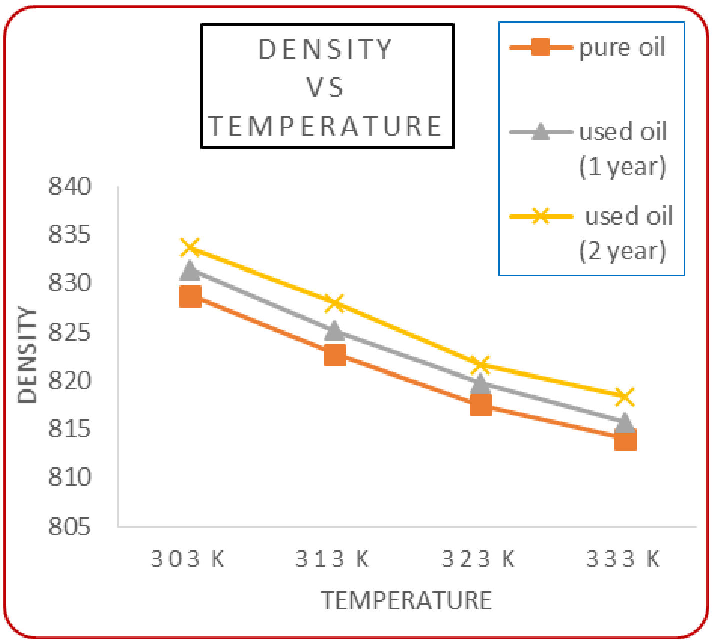

Fig-7 Variation of density with temperature

Table-2: Values of viscosity of oilsamplesin N.s.m^{-2}

Temperature(K)	Pure oil	Used oil (1 year)	used oil (2 year)
303 K	15.510	14.677	14.293
313 K	12.466	11.814	11.513
323 K	10.999	10.408	9.789
333 K	9.521	8.837	8.356

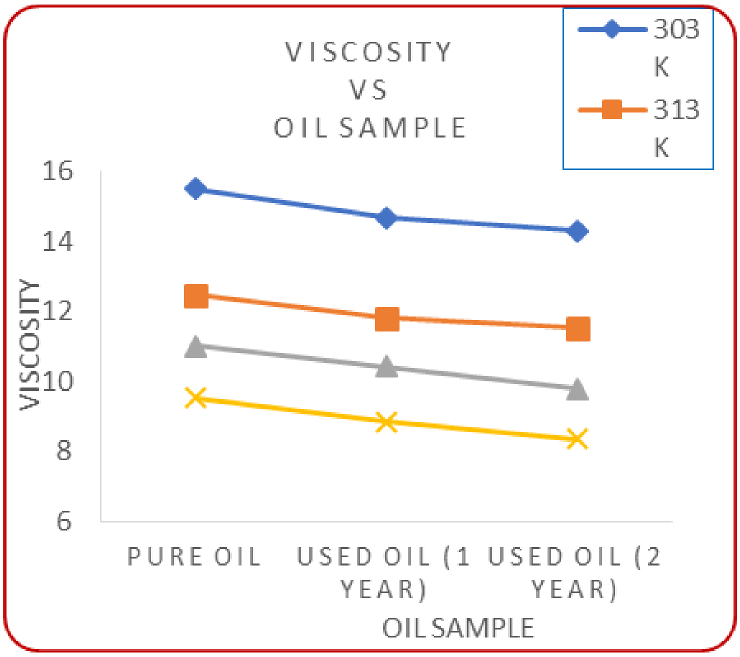

Fig-8 Variation of viscosity with oil samples

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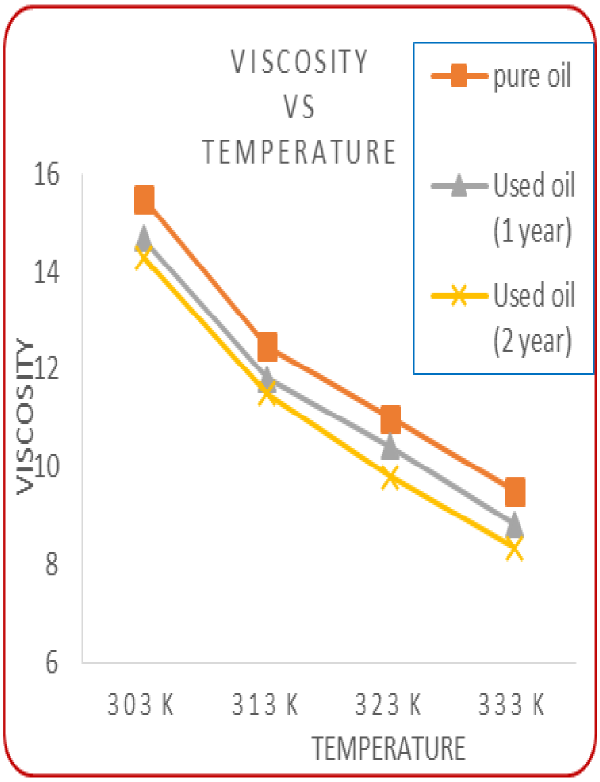

Fig-9 Variation of viscosity with temperature

The variation in the surface area of molecules, their relative velocity and their inner closeness are responsible for variation of density and viscosity of pure and used oil samples i.e., the structure of the molecule, and all theseperforman importantrole in determining these parameters. From fig.6. it can be understood that the density of pure oil sample is less and increases with age of the transformer because oil density depends on its composition, and composition of oil changes with aging. With increase in temperature, density of pure and used transformer oil samples decreases as shown in fig.7. As density is always inversely proportional to temperature. According to fig.8. Viscosity of the oil samples drops by small amount with aging of transformer oil. As shown in fig.9 with increase in temperature, viscosity of pure and used oil samples decreases. With increase in temperature, density and viscosity decrease which indicates that due to rise in thermal energy of the system their intermolecular forces decrease. This is the reason of increase in volume of the oil samples and hence decrease in density and viscosity.

Table-3: Values of breakdown voltage in KV and dielectric strength in KV/mm of oil samples.

Oil samples	Breakdown voltage (KV)	Dielectric strength (KV/mm)
pure oil	43.5	17.4
Used oil (1 year)	29.7	11.9
Used oil (2 year)	24.5	9.8

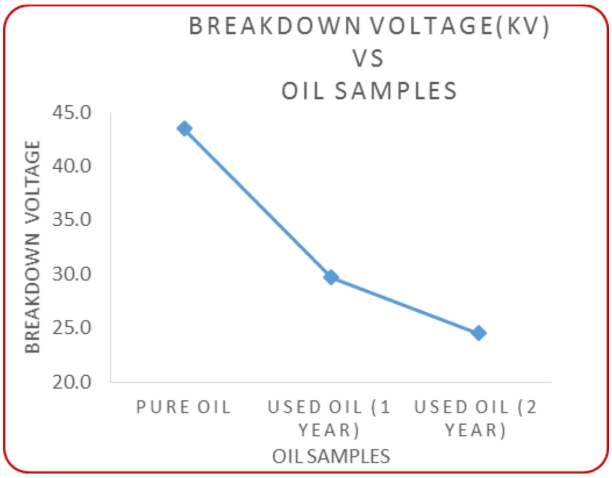

Fig-10 Variation of breakdown voltage with oil samples

According to fig.10.Pure oil sample shows higher value of breakdown voltage (BDV) than used oil samples and significantly decreases with age of the transformer. It indicates that pure oil or filtered oil have positive impact on transformer life. It is also suggested that online or offline oil filtration of power and distributed transformer must be carried out periodically to increase the life expectancy of transformer. It is known from the literature that the breakdown voltage or dielectric strength of transformer oil depends on the moisture content, suspended elements and cleanness of the oil samples [15-16].

Table-4: Values of Flash point and fire point of oilsamples in Kelvin.

Oil samples	Flash point(kelvin)	Fire point(kelvin)
Pure oil	427	457
Used oil (1 year)	423	447
Used oil (2)	417	441

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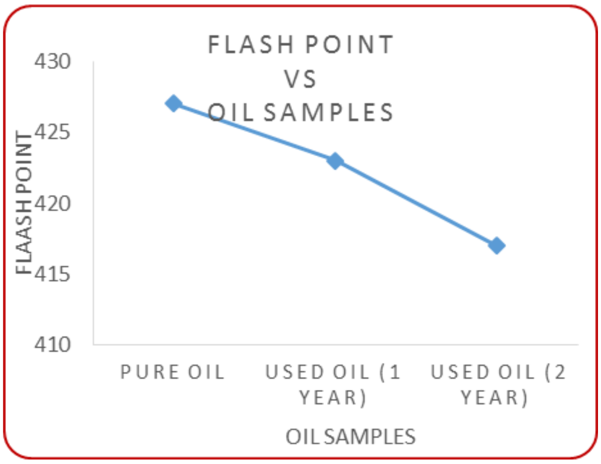

Fig-11Variation of flash point with oil samples

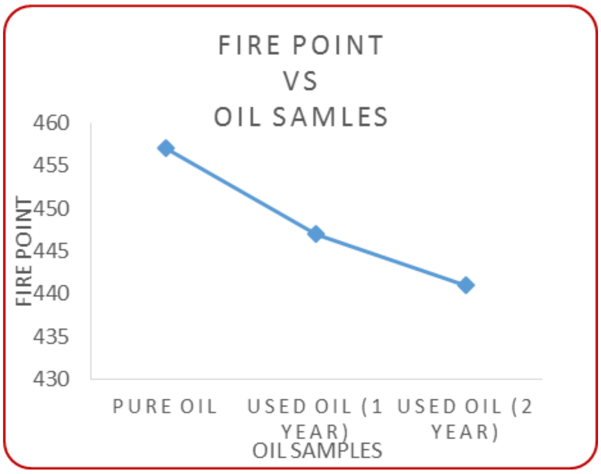

Fig-12Variation of fire point with oil samples.

According to fig 11-12, flash point and fire point value of pure oil sample is higher than the used oil samples and the value drop in small quantity with age of the transformer. The flash point and fire point valuesdrop in small amountduring the service time due to the existence of volatile combustible products in the oil. As flash point and fire point is directly related to viscosity, from the above graph it is clear that due to decreasing viscosity (fig.8) the flash point and fire point is also decreasing due to use of transformer. The decreasing trend conform that the continuous charging of transformer ionisation of oil occurs in a faster manner due to this there is a tendency of oil to catch fire at lower temperature rise if periodic filtration is not done, similarly due to ionisation that may lead to spark in winding as the flash point decreases with increasing in uses.

Table-6 Compounds present in 2mlpure transformer oil sample by X-rayfluorescence (XRF) technique.

Compounds	Concentration
Phosphorus (P)	258.3 ppm
Chlorine (Cl)	73.0 ppm
Calcium (Ca)	76.0 ppm
Tin (Sn)	43.8 ppm
Europium (Eu)	0.5 ppm
Sulphur (S)	0% or sulphur free
CH_2	99.949%

Table-7 Compounds presentin 2mlone year used transformer oil sample by X-ray fluorescence (XRF) technique.

Compounds	Concentration
Phosphorus (P)	279.6 ppm
Chlorine (Cl)	77.5 ppm
Calcium (Ca)	89.2 ppm
Tin (Sn)	45.9 ppm
Europium (Eu)	31.1 ppm
Sulphur (S)	0.157%
CH_2	99.788%

Table-8 Compounds presentin 2mltwo year used transformer oil sample by X-ray fluorescence (XRF) technique.

Compounds	Concentration in (ppm)
Phosphorus (P)	281.6 ppm
Chlorine (Cl)	83.1 ppm
Calcium (Ca)	98.5 ppm
Tin (Sn)	49.5 ppm
Europium (Eu)	49.1 ppm
Sulphur (S)	0.178%
CH_2	99.766%

From table-6, 7 and 8 it is concluded that pure transformer oil is sulphur free and used transformer oil contains some amount of sulphur. As pure oil does not contain any sulphur elements so sulphur present in used oil may either come from the rubber houses that are used during oil processing or from gasket materials. The existence of sulphur in oil can lead to corrosion in copper windings and on reaction with copper form copper sulphide which deposits on surface of paper insulation in transformer and can easily damage it. This leads to the insulation failure in transformer.

5.CONCLUSION:

In this work, the characteristics of pure oil sample collected after filtration and used oil samples coming from distribution transformers of one year and two year operating in the Khorda-Odishapower network, were analysed to assess the condition of the power transformer.

- Density of transformer oil increases by a small amount with operating period of the transformer and reduces with rise in temperature.
- Viscosity of transformer oil drops by small quantities with operating period of the transformer and decreases with rise in temperature.
- The breakdown voltage or dielectric strength of transformer oil significantly decreases with operating period of the transformer and thus had a greatestrelationship with the age of the transformer. In general, the life period of distribution transformer is 10 years, if oil filtration is done on periodic basis the life expectancy will increase to 2-3 years more.
- Flash point and fire point of pure and used oil samples illustrates the nature of higher thermal constancy in both pure and used oil samples. Hence, it concluded that, age of the transformer does not have a great impact on its flash point and fire point of the oil.
- X-ray fluorescence (XRF) demonstrates that the pure transformer oil is corrosive sulphur free and used transformer oil contains sulphur which may come from rubber housesthat are used during oil processing or from gasket materials. Sulphur amount increases with age of the transformer.

The outcomes of this investigationalexamination have revealed that after aging of the oil, significant degradation in the characteristics of transformer oil occur. So that the evolution of these parameters can be considered as aging sign of the transformer and suggested that online or offline filtration of the oilmust be done on periodic basis to extend the life period of the transformer.

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