Analysis of aged insulating oil for early detection of incipient fault inside the high voltage equipment

A thesis submitted in partial fulfilment of the requirements for the award of the degree of

Master of Technology
In
Power Control & Drives

By

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May 2013

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CERTIFICATE

This is to certify that the thesis entitled, **“Analysis of aged insulating oil for early detection of incipient fault inside the high voltage equipment”** submitted by **Ms. Shivani Hembrom** in partial fulfilment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in **“Power Control and Drives”** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: 24/05/13

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Declaration

I certify that

a) The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

d) Whenever I have used materials (experimental analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

e) Whenever I have quoted written materials from other sources, I have put them under quotation marks and given due credit to the sources by citing them and giving required details in the references.

Date:24/05/13

Shivani Hembrom

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Date: 24/05/13 Shivani Hembrom

Place: Rourkela

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ABSTRACT

Ageing of the transformer depends on several factors especially electrical and thermal stresses. Due to which incipient faults occurs which in turn if left undetected will cause deterioration and eventually lead to failure of the transformer. The presence of faults in transformer results in chemical decomposition of the transformer oil. The transformer oil is deteriorated due to the combination of the ageing process such as partial discharge (PD), electrical arcing and thermal ageing. The effects of different ageing processes and contamination of insulating oil of a transformer has been studied and verified using most popular optical method such as Ultra Violet (UV) Spectrophotometer and Fourier Transform Infrared (FTIR). The spectrums of UV spectrophotometer and FTIR have potential to analyse the oil quantitatively and qualitatively. In this work, two type of analysis is being carried out firstly the analysis of transformer oil which are aged with course of time during the transformer operation and secondly the analysis of laboratory aged transformer oil. Further, the analysis of the result of UV spectrophotometer and FTIR is carried out and finally ageing assessment using oil contamination level identification is given. The presented detection method has high potential to determine the types of faults occurred and their effect on the transformer oil by which the condition assessment can be performed easily.

LIST OF ABBREVIATIONS

PD	Partial Discharge
UV	Ultra Violet
FTIR	Fourier Transform Infra- Red
DGA	Dissolved Gas Analysis
HV	High Voltage
BDV	Break Down Voltage
KBr	Potassium Bromide
NaCl	Sodium Chloride
NMR	Nuclear Magnetic Resonance
HPLC	High Performance Liquid Chromatography

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Chapter 1

INTRODUCTION

Overview

Present chapter describes about the introduction of the project work. Also tells about the motivation and objective of the thesis. This chapter also summarizes the organisation of the thesis and the literature review on the study of ageing of the transformer oil is also discussed.

1.1 INTRODUCTION

Power transformer plays very important role in the transmission and distribution of electrical system. They need to be monitored periodically to prevent any potential fault inside the transformer. In the absence of the insulation diagnostics many transformer failed before reaching their designed technical life. The failure of such transformer costs several million dollars either to repair or to replace. In high voltage power apparatus one of the most common liquid insulating materials used for insulation is the transformer oil. Degradation of transformer oil is due to the combination of the ageing processes such as thermal ageing, electrical arcing and partial discharge (PDs) while it is under operation during its long period of service.

The insulating oil of HV equipment is degraded due to the combination of the ageing processes such as electrical arcing, thermal ageing and oxidation while it is operating in long period of service. Apart from the ageing process as described above, partial discharges are also responsible for insulation degradation process [1, 2]. The insulating property of the oil in HV power equipment is degraded due to the evolved gases such as Hydrogen (H_2), Nitrogen (N_2), Oxygen (O_2), Carbon Monoxide (CO), Carbon dioxide (CO_2), Methane (CH_4), Acetylene (C_2H_2), Ethylene (C_2H_4), Ethane (C_2H_6) produced during ageing processes [3,4]. The gases produced due to the ageing remain within the transformer oil in dissolved form. These gases are considered as key gases**.** These gases further indicate the existence of any one or combination of thermal, electrical, or corona faults. The rate at which each of these key gases is produced largely depends on the temperature and on the volume of material at that temperature. Thus, the concentrations of the individual dissolved gasses found in transformer insulating oil can be used to know the thermal history of the transformer to suggest any past or potential faults within the transformer.

Absorption spectroscopy refers to spectroscopic technique that measures the absorption of radiation as a function of frequency or wavelength, due to its interface with a sample. It is performed across the electromagnetic spectrum. Absorption spectroscopy is used to determine the presence of particular substance in a sample and also to quantify the amount of the substance present. Some of the common applications of this are Infrared and Ultraviolet – visible spectroscopy.

Aim of any absorption spectroscopy such as Fourier Transform Infrared (FTIR) or Ultra Violet Spectroscopy is to measure how well a sample absorbs light at each wavelength. In UV spectrophotometer many monochromatic beam of light of different wavelength are passed through the sample repeatedly and observed how much of the light is absorbed. It gives the contamination level in oil mainly due to the paper insulation which produces Furans, acids, water and other compounds on its deterioration. Ageing is also strongly dependent on the temperature, oxygen and water levels in transformer. And by controlling these, the transformer life can be extended. Water and furan are produced simultaneously and are the key indicators for the life anticipation of the power transformer. Presence of 0.5% moisture in paper and 20 ppm in oil are considered effective to cause sufficient dielectric degradation [5].

In FTIR spectroscopy, much simpler method is used to obtain the same result. Here rather than using a monochromatic beam of light at the sample, a beam containing many frequencies of light at once and then amount of beam absorbed by the sample is measured. Then the beam is modified to contain a different combination of frequencies which gives a second data point. This process is repeated many times and after that computer takes all the data and works backward to infer what the absorption is at each wavelength.

1.2 LITERATURE REVIEW

Various works has been done on the analysis of ageing of the transformer oil and methods have been suggested to be implemented on for smooth working and for determining the faults before any damage in the transformer. Thus it helps in the proper working of the power system. In 2000, the ageing process was explored and based on the spectral absorption characteristics a methodology for on- line transformer health assessment using ultraviolet absorption was developed [6]. A fuzzy logic based approach was given to estimate the age of a power transformer using key indicators such as moisture and furanic compounds in 2004 [5]. In 2011, operational strategy has been suggested to carryout diagnostics for the power transformer and distribution transformer for enhancement of the residual life of the in service transformer [7]. Also in 2011, study on the effect of different ageing processes on the optical absorption properties of insulating oil of a model transformer using UV spectrophotometer. And it is found that the optical quality of the transformer oil is mostly due to PDs [8].

1.3 MOTIVATION AND OBJECTIVE OF THE THESIS

Motivation

In high voltage power equipment, the insulation of the equipment plays the most important role in determining the condition of the power equipment. The insulation of equipment is monitored, designed and handled very carefully. For the insulation of power equipment such as transformers, switch gears, potential transformer, and current transformer etc. transformer oil is being used. It is also used for the cooling of the equipment. The transformer oil deteriorates due to various reasons such as partial discharge, thermal stresses and electrical arcing. Some other factors such as temperature and water content in the oil also results in the ageing of the transformer oil. Due to which many incipient faults occur in the transformer which in turn if left undetected will cause deterioration and eventually lead to failure of the transformer. The presence of faults in transformer results in chemical decomposition of the insulating materials. The transformer oil can be analysed using various methods such as UV spectroscopy and FTIR spectroscopy and the faults can be detected.

The main objective of the thesis is

- To analyse the aged transformer oil degraded during the transformer operation using UV spectrophotometer and FTIR.
- To analyse the laboratory aged transformer oil using UV spectrophotometer and FTIR.
- To analyse the results for the incipient fault detection and provide the condition of the transformer oil.

1.4 ORGANISATION OF THE THESIS

This thesis is organised into fine different chapters including introduction.

Chapter 1: This chapter includes the introduction, motivation and objective of the project. It also covers the literature review on the study of ageing of the transformer oil.

Chapter 2: This chapter describes about the basics of Transformer and properties of insulating oil used for cooling and insulation. It also covers the condition monitoring of the transformer and the diagnostic methods used for the analysis of the ageing of transformer oil.

Chapter 3: This chapter gives the experimental setup and analysis of the transformer oil aged during transformer operation and the laboratory aged transformer oil degraded thermally for different temperatures using the UV spectroscopy and FTIR spectroscopy.

Chapter 4: In this chapter results of the experiments are discussed carried out for the analysis of the aged insulating oil. Hence by analysing the spectrum obtained from UV and FTIR the condition of the transformer oil is determined and also tells about the incipient faults occurring in the transformer.

Chapter 5: Finally this chapter includes conclusion of the thesis work and the references.

Chapter 2

AGEING OF TRANSFORMER OIL

Overview

Present chapter describes about the transformer, types and properties of the transformer oil for healthy transformer. This chapter also throws light on the importance of condition monitoring of transformer. Various conventional and optical methods used for the prediction of transformer life based on the state of insulation are summarized.

2.1 TRANSFORMER

A transformer is a static electrical device that transfers energy between its winding circuits by magnetic coupling. The main objective of transformer is to transfer electrical power from one voltage level to another voltage level. It works on the principal of electromagnetic induction. The important components of the transformer are core, winding, insulation (solid or liquid). The transformer core provides a low reluctance path for magnetic flux linking the primary and secondary windings. The windings in the transformer are arranged in a manner reduce the leakage flux in the transformer. In spite of all these the core experience iron loss due to hysteresis and eddy current flow, which manifest themselves as heat. Mainly Mineral oil and Kraft paper is used for insulation of the transformer as these permit only a negligible current to flow through it.

2.2 PROPERTIES OF INSULATING MATERIALS

Some of the properties of the insulating materials are resistivity, breakdown voltage, permittivity and dielectric loss, etc. For an insulating material to be ideal, it should have following properties:

- High dielectric strength
- High resistivity
- Good thermal conductivity
- High tensile strength of solid insulation
- High degree of thermal stability

The insulating material should also have good mechanical properties such as ability to withstand moisture, vibration and bending. Also, it should have ability to withstand chemical attack and other adverse condition of service.

2.2.1 TRANSFORMER OIL

Oil used for insulation is mineral oil and it is obtained by fractional distillation and subsequent treatment of crude petroleum. Transformer oil helps mainly two purposes i.e. liquid insulation in transformer and it dissipates heat of the transformer i.e. act as coolant. In addition to these, oil also helps in two other purposes i.e. in preserving the core and winding as these are fully immersed in the oil and it also prevents direct contact of atmospheric oxygen with cellulose paper used for insulation of windings, which is prone to oxidation.

2.2.2 COMPOSITION AND TYPES OF TRANSFORMER OIL

Transformer oil are mainly composed of the saturated hydrocarbons known as paraffin whose molecular formula is C_nH_{2n+2} where n ranges from 20 to 40 and it also consist of cellulosic insulation material which is a polymeric substance whose molecular formula is $[C_{12}H_{14}O4(OH)_6]_n$ where n varies from 300 to 750.

Generally there are two types of Transformer Oil i.e. paraffinic transformer oil and naphthenic transformer oil. In our country generally paraffin transformer oil is used. Difference between these two types of transformer oil is naphtha oil is more easily oxidised than the other. But due to the oxidation the sludge formed gets easily dissolved than paraffinic oil. Another disadvantage of paraffinic oil is that it has high value of pour point due to wax content but this does not affect its use in India because of its warm climatic condition.

1.2.3 PROPERTIES OF TRANSFORMER OIL

Properties of transformer oil depend largely on some of the parameters and these should be considered in order to determine the condition of the transformer. These parameters are discussed as follows:

Water Content: Water is harmful in power equipment because it is attracted to the places of greatest electrical stress and it very much dangerous. Water accelerates the deterioration of both the insulation i.e. oil and paper. Degradation of the insulating paper results in the generation of more water.

Dielectric Strength: it is the measurement of the oils ability to with stand electrical stress without failure. Impurities such as water and conducting particles reduce the dielectric strength of insulating oil [9].

Acidity: Acids are generated in the oil due to oil decomposition. It can also come from external sources such as atmospheric contamination. These can induce corrosion inside the transformer in presence of water. The acidity of oil in a transformer should never be allowed to exceed 0.25 mg KOH/g oil [10, 11].

Interfacial tension: It measures the tension at the interface between two liquid which do not mix with each other and it is expressed in dyne/cm. Good oil will have interfacial tension in between 40 to 50 dynes/cm [12, 13].

Pour Point- It is the minimum temperature at which oil starts to flow. Pour Point of transformer oil is an important property mainly at the places where climatic condition is extremely cold. If the oil temperature falls below the pour point, transformer oil stops flowing and interrupts cooling in transformer.

1.2.4 INSULATING OIL QUALITY

A combination of electrical, physical and chemical tests is performed to measure the change in the electrical properties, contamination level, and the degree of deterioration in the insulating oil. The results are used to avoid costly and untimely equipment failure, and to increase the life of the equipment. As the paper degrades, a number of specific furanic compounds are produced and dissolved in the oil. Furan and phenol measurement in oil is a convenient method to assess the condition of the paper insulation. Transformer oil samples should be analysed for furans and phenols when one or more of the following conditions exist:

- Overheating or overloading,
- High concentration of carbon monoxide or carbon dioxide,
- Rapid decrease of interfacial tension with respect to acid number,
- Gradual darkening of the oil
- Abrupt increase of the moisture content of the oil.

1.3 CONDITION MONITORING OF TRANSFORMER

Condition Monitoring of Transformers is the process of achievement and management of data related to various properties of transformers so as to detect the failure of a transformer and take protective and preventive measures by observing the irregularity of the transformer parameters from their expected values. Transformers are the most important assets of electrical power system and could cause power failures, personal and environmental hazards. Interruptions and failure of transformer is due to dielectric breakdown, deformation in winding caused by electrical instability, weakening of insulation, lightning, insufficient maintenance, loose connections, overloading, bushings, etc.[14]. The important aspects of condition monitoring of transformers are:

1. Thermal Modelling
2. Dissolved Gas Analysis
3. Frequency Response Analysis
4. Partial Discharge Analysis

Testing of insulating oil is one of the most common tests used to evaluate the condition of transformers in service. Thermal and electrical faults lead to degradation of the oil. The dissolved gas analysis test is one of the important techniques for condition monitoring of transformers.

2.3.1 DISSOLVED GAS ANALYSIS

Whenever electrical power transformer goes under thermal and electrical stresses, some gases are evolved due to decomposition of transformer oil, when the fault is severe, the production of evolved gases are more and they get collected in Buchholz relay. But when the faults are minor and the concentration of the gasses is not high then it will get enough time to get dissolved in the transformer oil. Hence by monitoring the Buchholz relay only it is very difficult to predict the condition of the electrical power transformer. Thus it becomes important to analyse the quantity of different gasses dissolved in transformer oil in service periodically. By using Dissolved Gas Analysis of transformer oil, one can obtain the actual condition of a transformer. It is desirable to conduct the DGA test of transformer oil in routine manner to get earlier information about the trend of deterioration of transformer health and life.

Actually in DGA test, the gases dissolved in oil are extracted from oil and examine the quantity of gasses in a specific amount of oil [15]. By observing the amount of different gasses dissolved in the transformer oil, one can conclude about the condition of transformer.

Generally the gasses found in the transformer oil are hydrogen (H_2), methane (CH_4), Ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_3), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2) [16].

Mostly two methods used for determining the composition of these gases in transformer oil are using a Vacuum Gas Extraction Apparatus and Gas Chronographs. By these apparatus first gasses are extracted from oil by stirring it under vacuum. Then these gasses are then fed into gas Chronographs for measurement of each gas.

Generally it is found that hydrogen and methane are produced in large quantity if internal temperature of power transformer rises up to 150°C to 300°C due to abnormal thermal stresses. If temperature goes above 300°C, ethylene (C_2H_4) is produced in large quantity. At the temperature is higher than 700°C large amount of hydrogen (H_2) and ethylene (C_2H_4) are produced. Ethylene (C_2H_4) is indication of very high temperature hot spot inside the transformer. If in DGA test, CO and CO_2 are found in large quantity it is predicted that there is decomposition of proper insulation.

Chapter 3

EXPERIMENTAL SETUP

Overview

This chapter describes the experiments carried out for the analysis of degraded transformer oil during the transformer operation. This chapter also describes the preparation of sample and fabrication of the oven to carry out the accelerated ageing studies on transformer oil. The samples are kept in the air circulated oven for accelerating thermal stress at 60°C, 120°C and 150°C for 3 hrs. And analysis of the thermally aged transformer oil using various optical methods such as UV spectrophotometry and FTIR spectroscopy is also described.

3.1 DEGRADED TRANSFORMER OIL

Here in this work two samples of transformer oil are taken which are degraded during the transformer operation and they are compared with the new transformer oil. These samples are then analysed in FTIR and UV spectrophotometer and the spectrums are recorded and discussed. The specification of the transformer oil samples taken is given as follows:

Table 3.1: Description of transformer oil sample

Sl. No.	Name of the Sample	Sample Description
01	Sample 1 – S1	New Transformer Oil
02	Sample 2 – S2	Transformer oil with high concentration of acetylene
03	Sample 3- S3	Oil from the transformer operating since 35 years

1.2 THERMALLY AGED TRANSFORMER OIL

1.2.1 SAMPLE PREPARATION

As shown in Fig.3.1, thermal aging tests were performed on samples of mineral transformer oil. To avoid the contamination of the oil samples, small glass conical flasks of 150 mL were cleaned and dried. Then the clean conical flasks were then filled with 75 mL of new transformer oil, oil with copper and paper separately and were sealed with aluminium leaf.

Figure 3.1: Photograph of the test samples

The flasks were then placed in controlled oven at different temperatures of 60°C, 120°C and 150°C for the duration of 3 hours. The description of the samples prepared is given in the Table 3.2.

Table 3.2: Description of sample prepared

Sl. No.	Name of the Sample	Sample Description
01	Sample 1 – TO-1	Pure Transformer Oil
02	Sample 2 – TO-2	Transformer oil with copper
03	Sample 3 - TO-3	Transformer oil with Kraft Paper

1.3 DETECTION TECHNIQUES OF AGED TRANSFORMER OIL

There are many detection techniques to analyse the aged transformer oil which have been used by many researchers and obtained influential results. Here in this work absorption spectroscopy is used. Absorption spectroscopy refers to spectroscopic technique that measures the absorption of radiation as a function of frequency or wavelength, due to its interaction with a sample. It is performed across the electromagnetic spectrum. Absorption spectroscopy is used to determine the presence of particular substance in a sample and also to quantify the amount of the substance present. Some of the common applications of this are FTIR and Ultraviolet – visible spectroscopy.

1.3.1 FOURIER TRANSFORM INFRARED (FTIR) SPECTROSCOPY

IR absorption positions are generally presented as either wavenumbers (ν) or wavelengths (λ). Wavenumbers defines the number of waves per unit length. Thus wavenumbers are directly proportional to the frequency. Wavenumber and wavelengths can be interconnected using the following equation:

$$\nu \text{ (in cm}^{-1}) = \frac{1}{\lambda \text{ (in μm)}} \times 10^{-4} \text{.......................... (1)}$$

Transmittance T is the ratio of radiant power transmitted by the sample (I) to the radiant power incident on the sample (I_o). Absorbance (A) is the logarithm to the base 10 of the reciprocal of the transmittance (T). And it is given by the following equation:

$$A = \log_{10}\frac{1}{T} = -\log_{10} T = -\log_{10}\frac{I}{I_o} \text{.................. (2)}$$

The transmittance spectra provide better contrast between intensities of strong and weak bands because transmittance ranges from 0 to 100 % T whereas absorbance ranges from infinity to zero. The IR region is commonly divided into three smaller regions.

	Near IR	Mid IR	Far IR
Wavenumbers (cm^{-1})	13000-4000	4000-400	400-10
Wavelengths (μm)	0.78-2.5	2.5-50	50-1000

Here FTIR records the absorption spectrum in the region from 400 to 4000 cm^{-1}[17-20].

1.3.1.1 SCHEMATIC DIAGRAM FOR FTIR

The schematic setup for FTIR is shown in the Fig. in which the IR radiation from a broadband source is first directed into an interferometer, where it is divided and then recombined after the split beams travel different optical paths to generate constructive and destructive interference. Next, the resulting beam passes through the sample compartment and reaches to the detector. Hence the spectrum is obtained and analyzed.

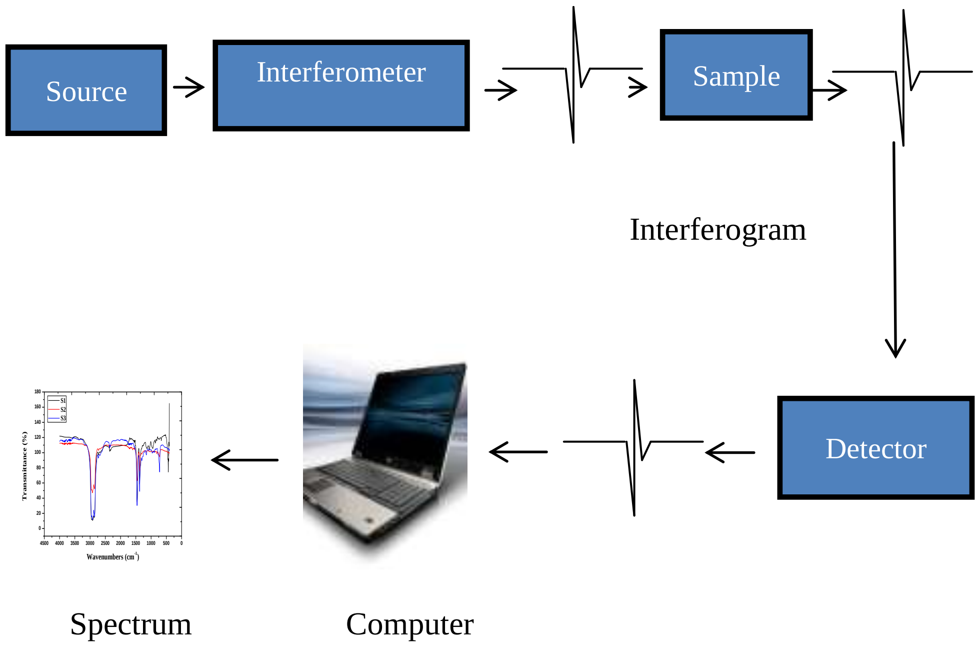


Figure 3.2: Schematic setup for FTIR

1.3.1.2 PROCEDURES

Firstly a background spectrum is obtained is shown in the Fig. 3.2. Here KBr is used as the background. Because KBr is the only material which has no absorption bands in IR region. An important disadvantage of KBr is its extreme sensitivity to moisture.

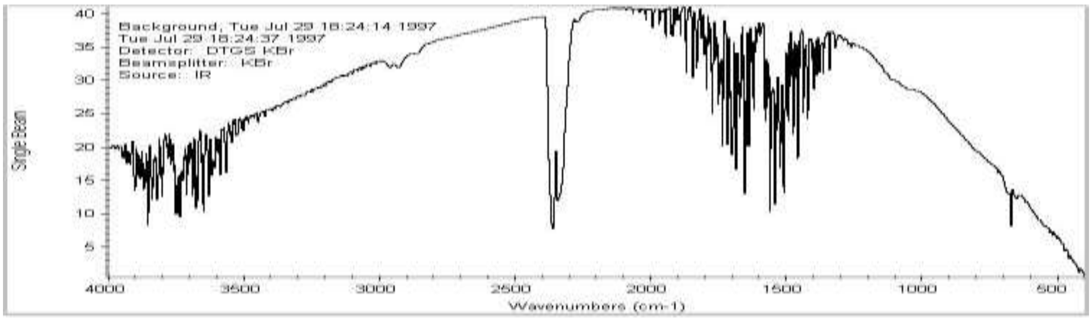


Figure 3.3: A typical FTIR background spectrum

It is time consuming to work with, but the spectrum has the best quality. It is necessary to obtain the background spectrum because moisture and the gases from the environment get accumulated in the sodium chloride (NaCl) plate which is shown in the Fig. 3.4, and it will contribute information that is not our sample. Secondly, a drop of transformer oil is squeezed in the Sodium Chloride (NaCl) plate to form a film of approximately 0.01 mm in thickness.

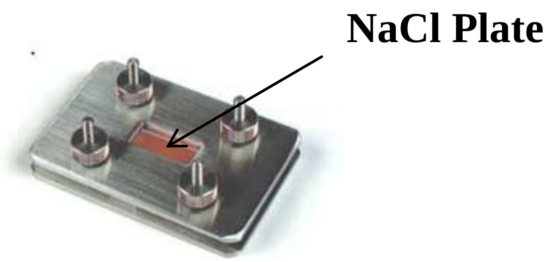


Figure 3.4: Photograph of the clamp of NaCl plate

Then the NaCl plate is clamped in the screw tightened holder and then a single beam spectrum of the sample which will contain absorption bonds from the sample as well as the background was collected and lastly the ratio between the single beam spectrum and the single beam background spectrum gives the spectrum of the sample and the data analysis is done.

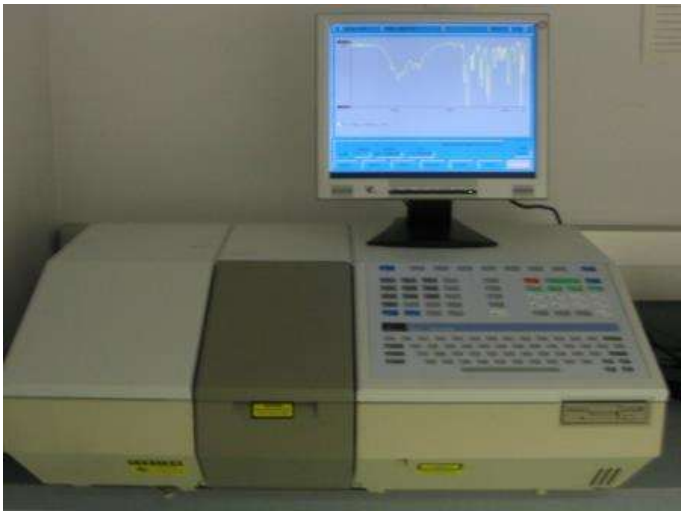


Figure 3.5: Photograph of the FTIR spectrometer

In the Fig. 3.5 the photograph of FTIR spectrometer is shown. In the IR spectrum there are certain characteristics of bonds that are dependent upon the complete structure, namely the wavelength and amount of energy absorbed. The infrared spectrometer gives an understanding of the structure and bonding present in a molecule by looking at the vibrational motions of which it undergoes. Infrared spectroscopy only work for compounds that have a dipole moment. The peaks on the IR spectrum correspond to the energies absorbed by the various functional groups. By noting the functional groups in a molecule, interpretation of an IR spectrum can indicate the identity of a molecule by the presence or absence of such peaks.

1.3.2 ULTRA VIOLET (UV) SPECTROSCOPY

Ultra violet and visible spectroscopy is also known as electronic spectroscopy and it works on the same principle as FTIR. It is based on the fact that electrons in certain types of chemical bonds are excited from the ground state when exposed to radiation in the wavelength range of 200 – 800 nanometer (nm). It is primarily used to measure the multiple bond and aromatic conjugation within molecules. Ultraviolet spectrum records the wavelength of an absorption maximum, i.e., λ_{max} and the strength of the absorption, i.e., molar absorptivity as defined by the Beer – Lambert's law [21] expressed in equation (1):

$$\boldsymbol{A = -\log_{10} T = -\log_{10}\left(\frac{I}{I_o}\right) = \varepsilon c l} \qquad \text{………………….. (3)}$$

Where: A is the absorbance of the solution

T is the transmittance of the solution

I is the incident light intensity

I_o is the transmitted light intensity ε is the molar absorptivity

c is the concentration of solute

l is the path length of the sample

1.3.2.1 SCHEMATIC DIAGRAM FOR UV SPECTROPHOTOMETER

Schematic setup of UV spectrophotometer is shown in the Fig.3.6 it shows the diffraction of the UV light into the reference cell and the sample cell and recording of the UV spectrum. The light is split into two beams before it reaches the sample. One beam is used as the reference and the other beam passes through the sample. The reference beam intensity is taken as 100 % Transmittance (or 0% absorbance) and the measurement displayed is the ratio of the two beam intensities.

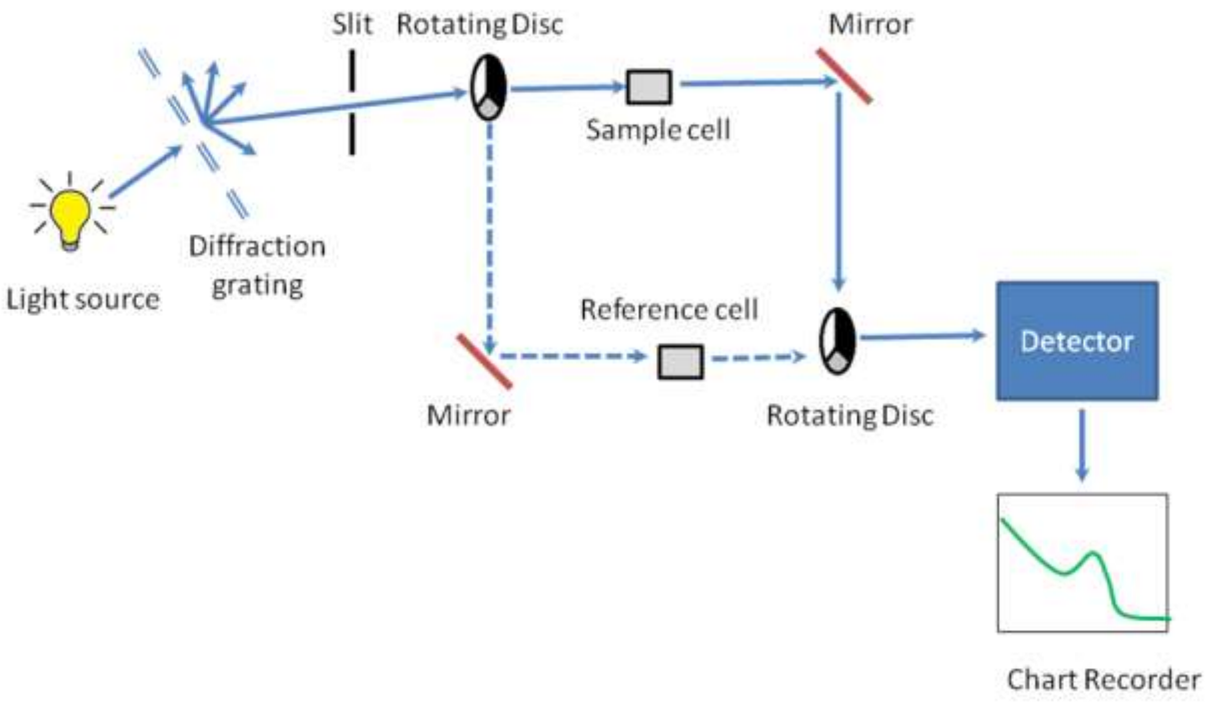


Figure 3.6: Schematic setup of UV spectrophotometer

1.3.2.2 PROCEDURES

Here in this experiment Shimadzu corporation UV-2450 PC (220 V) is used for analysing the transformer oil which is shown in the Fig. 3.7.

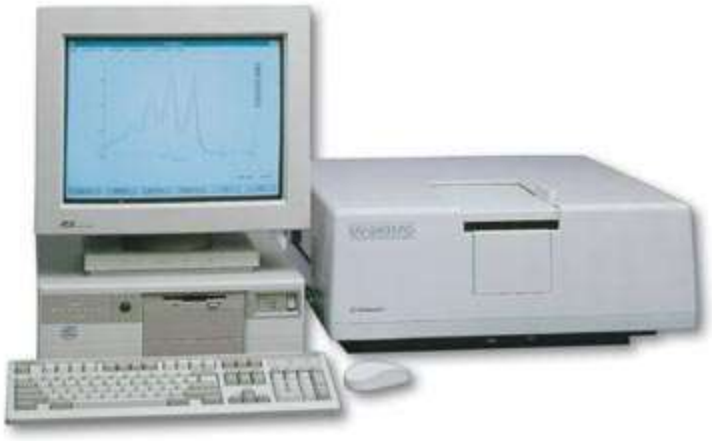


Figure 3.7: Photograph of UV spectrophotometer

In this experiment two identical quartz cuvettes is used for measurement of optical transmission in which one cuvette is taken as reference cuvette and another is taken as sample cuvette. Here acetone is taken as the solvent for the transformer oil. First the UV light is passed through the reference cuvette and then transformer oil samples are analysed after that.

Transformer oils are very complex mixtures and may consists of as many as 2900 paraffinic, naphthenic and aromatic hydrocarbon molecules types. But the paraffin and naphthenic compounds do not absorb in the near UV region i.e. 200 – 380 nm. In these region only aromatic compounds in the transformer oil absorbs. The UV spectrophotometry provides reasonable information on the health of the power transformer to plan the cost effective maintenance and operational criteria. It also provides overall assessment of the transformer with precision and interrelation between the transformer ageing [7,21].

Chapter 4

RESULTS AND DISCUSSION

Overview

In this chapter results of the experiments are discussed which are carried out for the analysis of the aged insulating oil. Hence by analysing the spectrum obtained from UV and FTIR the condition of the transformer oil is determined and also tells about the incipient faults occurring in the transformer.

4.1 DEGRADED TRANSFORMER OIL

4.1.1 ANALYSIS USING FTIR

In Fig 4.1, theoretical absorption characteristics of two different types of aged transformer oil are being compared with that of the new transformer oil and it is found that in the IR region, the deformation in the degraded transformer oil significantly changes its absorption spectra. Due to the degradation of the transformer oil there is increase in the absorption at certain wavelength and hence it tells about the presence and absence of the compound due to deterioration of the oil.

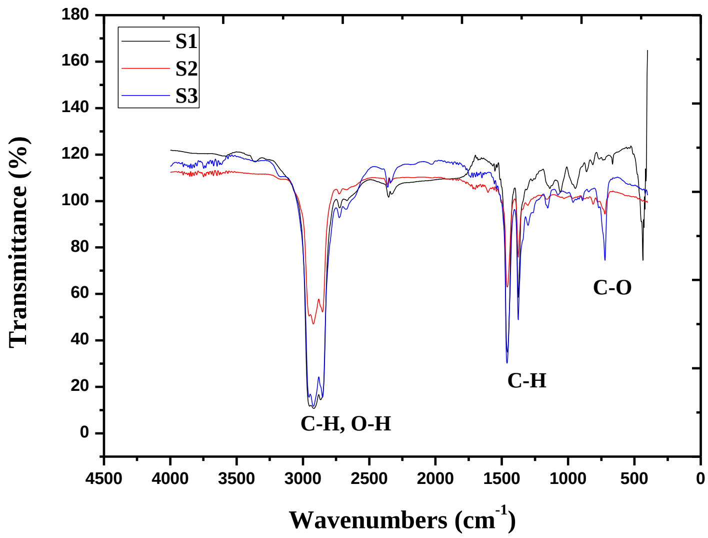


Figure 4.1: Spectral Response of Transformer Oil Using FTIR

From Fig 4.1, it is seen that there are peaks at which says about the presence of C-O bending of CO_2 and C-H stretching of CH_4 and C_2H_4 corresponding the wavenumbers 610-725 cm^{-1}, 2840-3230 cm^{-1} and 1420-1468 cm^{-1} respectively [22]. In case of sample S3 which is the transformer oil from the transformer operating since 35 years has degraded largely and it confirms the presence of CO_2, CH_4 and C_2H_4. In sample S2 also contains the gases but in less quantity. Also with the ageing of the transformer oil the colour also changes. The change of colour of the transformer oil is due to the decomposition of the paraffin and the naphthenic compounds and formation of aromatic compounds in the oil which changes the refractive mode of the transformer oil samples and produces absorption. Therefore, the high voltage power equipment requires lots of care and prevention from the ageing of the transformer oil which is responsible for degradation of insulation properties.

4.1.2 ANALYSIS USING UV SPECTROSCOPY

The absorbance spectrum provides a measure of how much light is absorbed by the oil sample. The absorbance A_λ is calculated as

$$A_\lambda = -\log_{10}\frac{S_\lambda - D_\lambda}{R_\lambda - D_\lambda} \quad (2)$$

Where S is the sample intensity at wavelength λ, Dis the dark intensity at wavelength λ, r is the reference intensity at wavelength λ [22].

From the above Fig4.2, we can conclude that the new transformer oil absorbance exhibits its characteristics maximum absorption at 335 cm^{-1}. The UV - spectrophotometry for other transformer oil samples which are being degraded due to various ageing process.

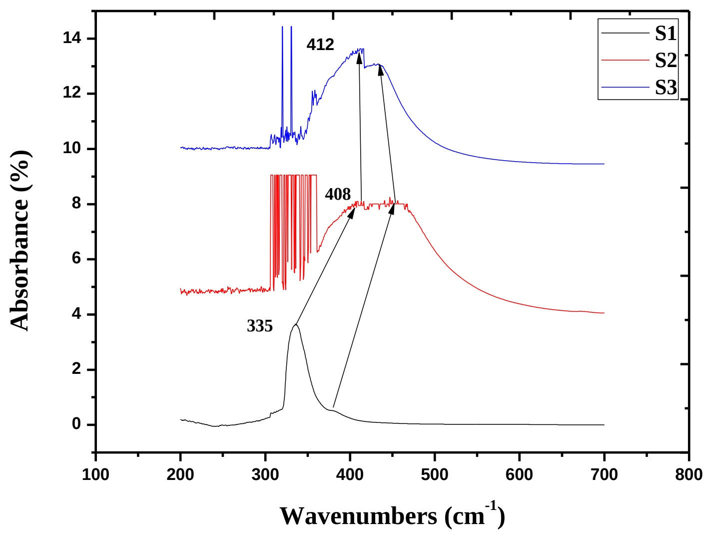


Figure 4.2: UV Spectrum for different aged transformer oil absorbance

Here three samples are taken in which one is the transformer new oil and other two are the samples of oil which are degraded due to various reasons in course of time during transformer operation. The spectrum represents that the absorbance increases with the oil deterioration and contamination due to ageing properties of the insulation system (oil + cellulose). Also the bandwidth for the maximum absorbance increases and there is a wavelength shift as well with the increase in age of transformer oil. In sample S2 of transformer oil there is absorption between 350 – 565 cm^{-1} with maximum absorption at 408 cm^{-1} and in sample S3 we can clearly see that the maximum absorption takes place at 412 cm^{-1} which shows there is shifting in the wavelength with oil degradation. Also there considerable noise from 300 – 350 cm^{-1}

range in the samples S2 and S3 which is mainly due to the variety of contamination including very high content of carbon and water. Thus oil condition can be interpreted from scrapped to excellent.

4.2 ANALYSIS OF LABORATORY AGED TRANSFORMER OIL

4.2.1 ANALYSIS USING FTIR

4.2.1.1 Spectral response of Transformer oil samples heated at 60˚C for 3hrs

In the Fig. 4.3, the spectral response for the transformer oil samples which were being heated at 60˚C is shown. From the figure it is concluded that there is very less change in the transformer oil at this temperature only there is slight change in the absorption of the transformer oil having copper in it. And the pure transformer oil and the oil with paper are having almost same absorption at almost each wavelength.

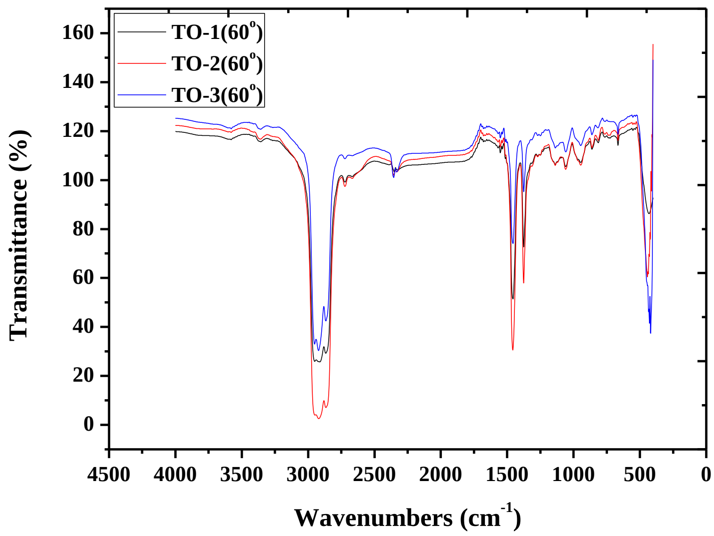


Figure 4.3: Spectral response of transformer oil samples at 60˚C

4.2.1.2 Spectral response of transformer oil samples heated at 120˚C for 3hrs

In the Fig. 4.4 the spectral response of the transformer oil samples which are heated at 120˚C for 3hrs are shown. It is clear that at this temperature also no considerable change is seen in the spectrum and spectrum for all the samples are almost overlapping on each other.

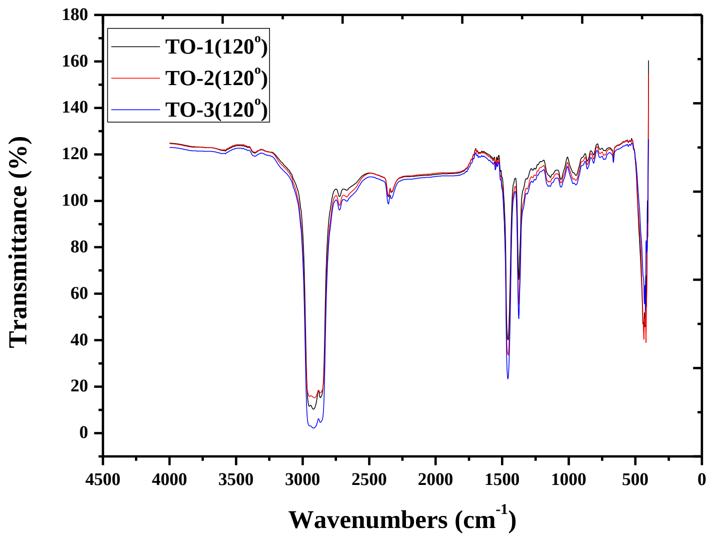


Figure 4.4: Spectral response of transformer oil samples heated at 120°C

4.2.1.3 Spectral response of transformer oil samples heated at 150°C for 3 hrs

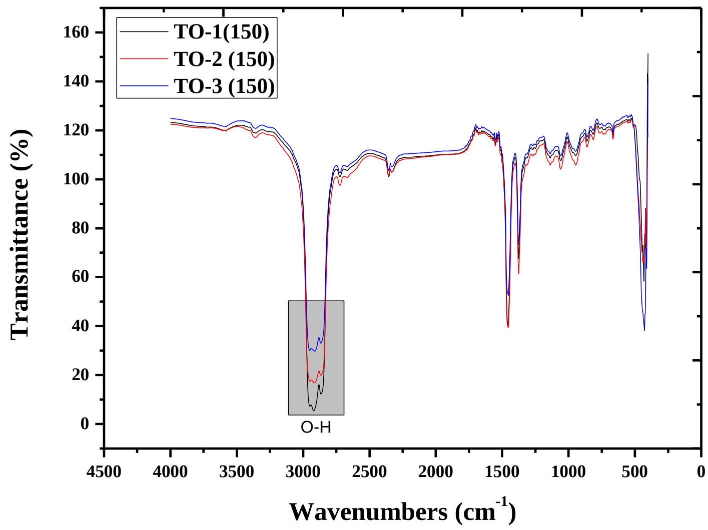


Figure 4.5: Spectral response for transformer oil samples heated at 150°C

The three samples heated at different temperature are then analysed in the FTIR and the spectral response is recorded. It is clear from the above Fig 4.3 and Fig. 4.4 that the samples heated at 60°C and 120°C does not show any considerable change but in case of Fig. 4.5 the transmittance for different samples of transformer oil increases that is there is decrease in the absorption level with the change in the concentration of the transformer oil. The zoomed view of the selected are of Fig 4.5 is shown in the Fig. 4.6.

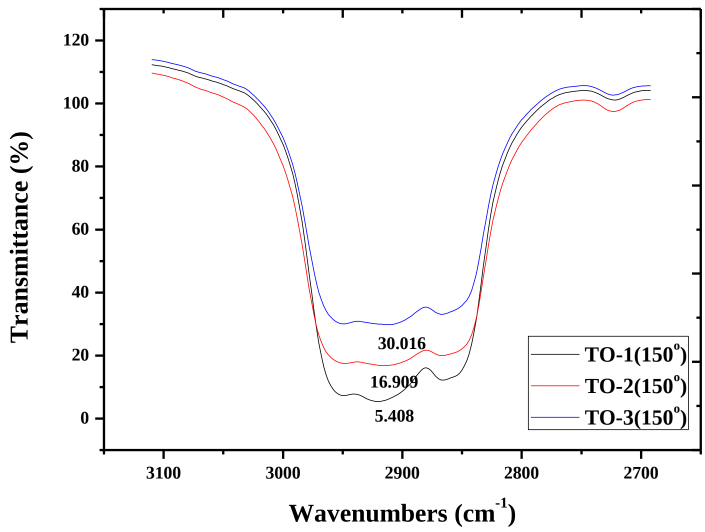


Figure 4.6: Showing the selected area of Fig. 4.5

Hence clearly the transformer oil with copper i.e. TO-3 have highest transmittance of 30.016 %, transformer oil with Kraft paper i.e. TO-2 has transmittance of 16.909% and pure transformer oil has transmittance of 5.408% i.e. lowest among all. The absorbance is the reciprocal of the transmittance. It is known that due to decomposition of Kraft paper in the transformer oil furanic compounds are generated and gets dissolved and hence the sample TO-3 shows high transmittance.

4.2.1.4 Spectral response of the pure transformer oil heated at different temperature.

In the Fig.4.7, spectral response of the pure transformer oil is heated at different temperature is shown. It is clear that there is no change in the transformer oil with temperature and the spectrums at each temperature just overlaps each other. Only a slight change in the absorption of the transformer oil heated at 150°C can be seen.

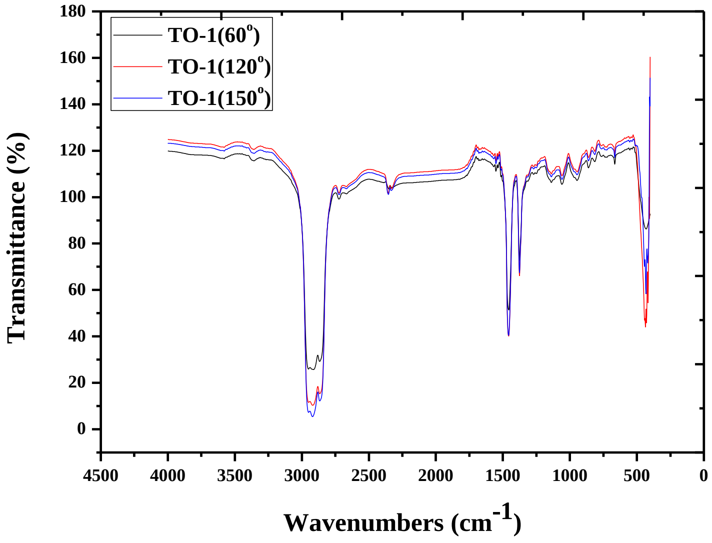


Figure 4.7: Spectral response pure transformer oil at different temperature

4.2.1.5 Spectral response of the transformer oil with Cu heated at different temperature

In the Fig. 4.8, the spectral response for the transformer oil mixed with copper which is heated at different temperature is shown. In the transmittance spectrum with the aging in the oil the transmittance decreases hence at 120°C the oil shows some changes with respect to other spectrums at different temperature.

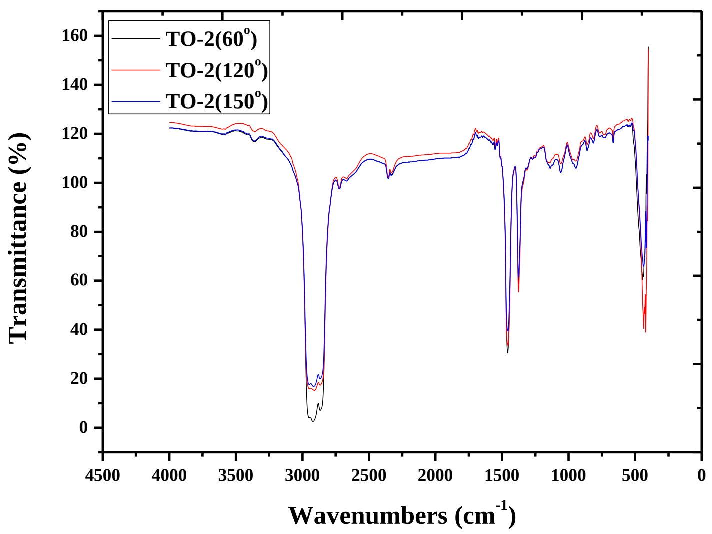


Figure 4.8: Spectral response of transformer oil with Cu at different temperature

4.2.1.6 Spectral response of the transformer oil with paper heated at different temperature

In the Fig.4.9, the spectral response of the transformer oil mixed with Kraft paper which is heated at different temperature is shown. Here the Kraft paper is used for the insulation purpose in the transformer so with its decomposition many furanic compounds gets dissolved in the transformer oil so it is observed that the changes are not so considerable but there is slight increase in absorbance in case of 150°C which tells about presence of some impurities in the transformer oil with paper with increase in temperature.

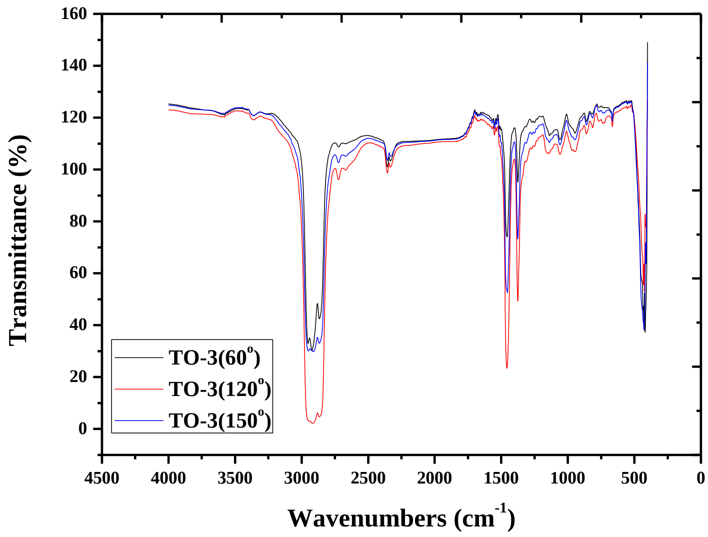


Figure 4.9: Spectral response of transformer oil with Kraft paper heated at different temperature

4.2.2 ANALYSIS OF THERMALLY AGED TRANSFORMER OIL USING UV SPECTROPHOTOMETER

4.2.2.1 Absorbance Spectrum for Transformer oil Samples heated at60°C for 3 hrs

In the Fig. 4.10, the UV absorption spectrum for the transformer oil samples which were heated at 60°C for 3hrs is been shown. Here clearly it is inferred that there is no absorption in the sample which supports the FTIR results that there is no considerable change in the sample.

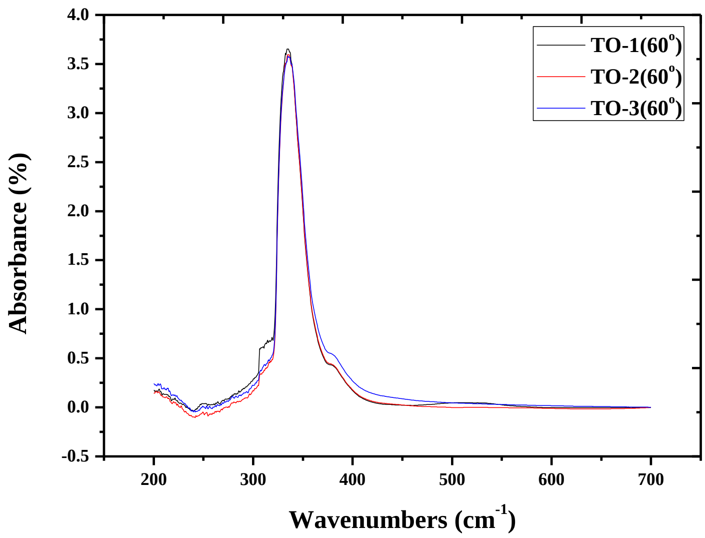


Figure 4.10: UV spectrum for Transformer oil Samples heated at 60°C

4.2.2.2 Absorbance Spectrum for Transformer oil samples heated at 120°C for 3 hrs

In the below Fig. 4.11 the absorption spectrum for the transformer oil samples which are heated at 120°C are shown. It is concluded that the transformer does not experience much change up to this temperature and there no impurities formation in the oil samples.

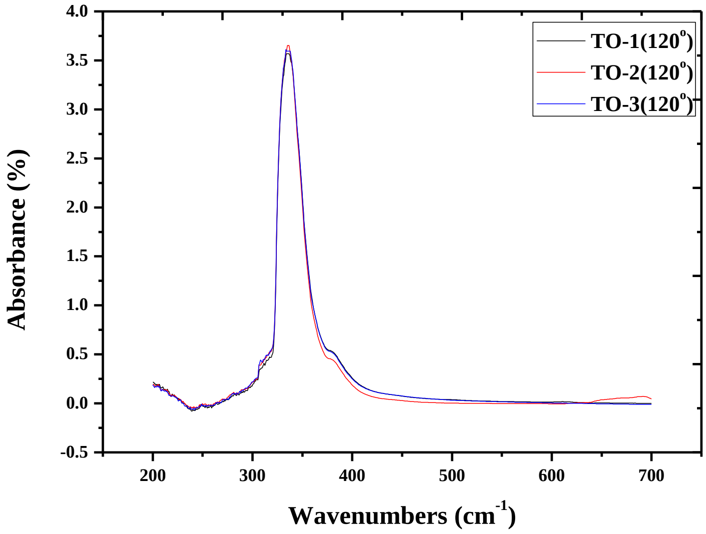


Figure 4.11: UV spectrum for transformer oil samples heated at 120°C

4.2.2.3 Absorbance Spectrum for Transformer oil samples heated at 150°C for 3hrs

In Fig. 4.12, the absorption characteristics of the three samples heated at 150°C for 3hrs were tested in UV spectrophotometer. It is found from this study that the quality of the transformer oil is degraded with increase in the temperature and composition of the oil.

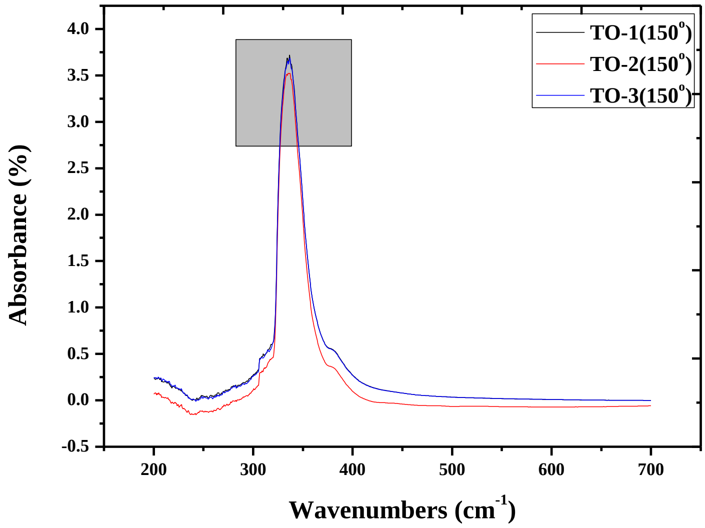


Figure 4.12: UV spectrum for transformer oil samples heated at 150°C

There is no considerable change in the absorption spectrum of the three samples up to 120°C shown in Fig. 4.10 and Fig. 4.11. Copper and Kraft paper in transformer are used for the winding and insulation purpose, so this analysis shows the effects on transformer oil due to these substances under thermal effect. As the temperature increases the copper and paper gets decomposed, due to which the composition of transformer oil changes, thus changing the absorption level. The selected portion in Fig. 4.12 shows the absorption peaks of the various samples heated at 150°C for 3hrs.

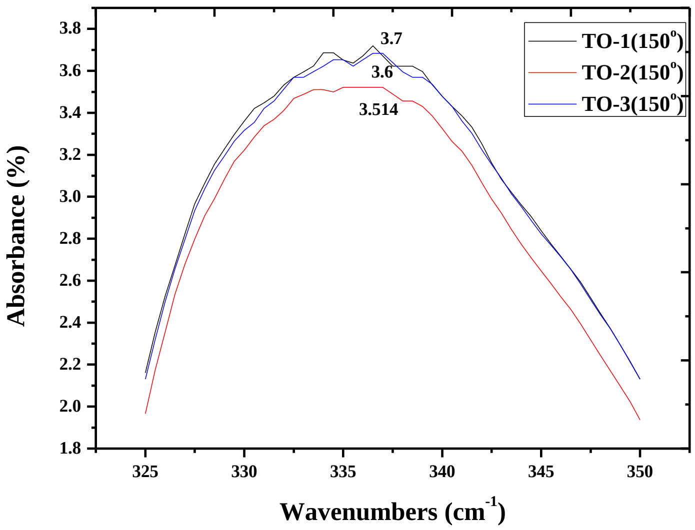
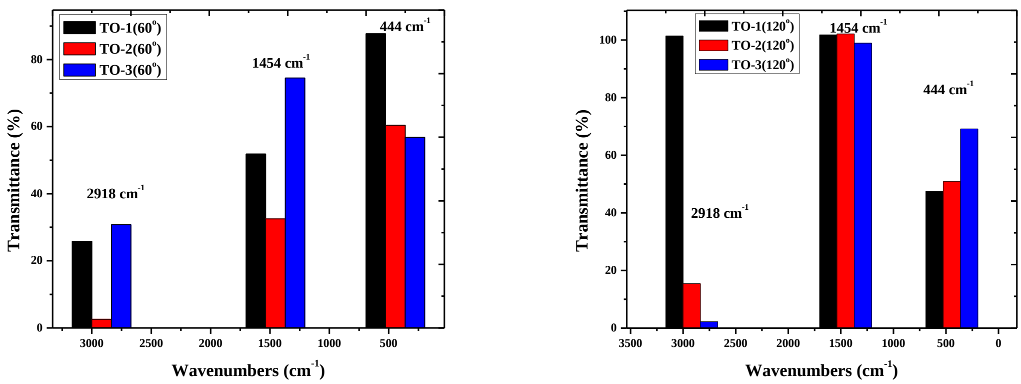


Figure 4.13: Showing selected area of Fig. 4.9

The UV spectrometry technique is used in this study for the detection of the interpretation of the contamination level for the transformer oil. Also extension of life is possible leading to proper asset management and good capital investment can be achieved

4.2.3 Transmittance at various wavenumbers

Here in Fig. 4.14 bar lot is shown for the transmittance at various wavenumbers for different transformer oil samples at different temperature. At 60°C the sample TO-1 transmittance is highest and TO-2 has lowest which means absorbance in case of TO-2 is maximum thus it is undergoing maximum changes with temperature. At 120°C, the TO-1 is having maximum transmittance that means it is having less absorbance and it is undergoingvery less changes with increase in temperature.



(a)

Figure 4.14: Transmittance at different wavenumbers for different transformer oil samples at (a) 60° (b) 120°

In the Fig.4.15, the bar plot for the transmittance at different wavenumbers for different transformer oil at 150°C and bar plot for the transmittance at different wavenumbers for pure oil heated at different temperature. In the Fig. 4.15 (c), there is minimum transmittance in case of TO-3 that means it is undergoing maximum changes with temperature and has maximum absorbance. In Fig. 4.15(d), the bar plot shows absorbance at 444 cm^{-1} is maximum and the lowest absorbance at 2918 cm^{-1}, it shows with increase in the wavelength the absorption is increasing.

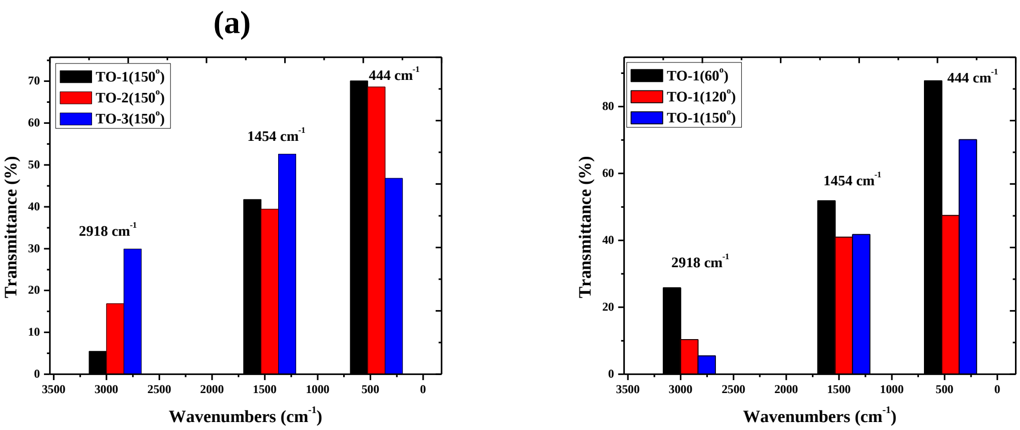


Figure 4.15: (c) Transmittance at different wavenumbers for different transformer oil samples at 150 °and (d) Transmittance at different wavenumbers for pure transformer oil at different temperature

In the Fig. 4.16, bar plot for the transmittance at different wavenumbers for transformer oil with copper and Kraft paper is shown. In case of the transformer oil with copper there is increase in the absorption with increase in wavelength and also with increase in temperature absorption is increasing. In case of transformer oil with Kraft paper absorption is almost same for the wavenumbers taken in consideration that is there is only slight change in the wavenumbers. Also with increase in temperature there is very less change in the absorption.

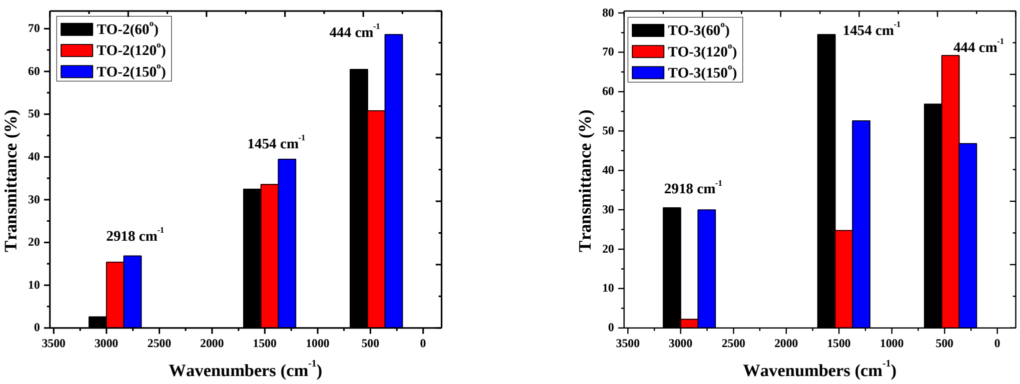


Figure 4.16: Transmittance at different wavenumbers at different temperature for (e) transformer oil with Cu and (f) Transformer oil with Kraft paper

Chapter 5

CONCLUSION

Overview

In this chapter, an attempt has been made to correlate the properties of insulating oil under thermal stress. The variation of transmittance and absorption at different wavelength is being discussed. An effort has been made to find out the type of fault occurred in the transformer by the analysis through FTIR and UV spectroscopy. Hence the condition of the transformer is being accessed.

5.1 CONCLUSION

The FTIR spectroscopy is used here to study the effect of ageing in the insulating oil using principle of light absorption. Therefore from the above study it is inferred that the degradation of the transformer oil results in formation of gases like carbon dioxide (CO_2), methane (CH_4) and ethylene (C_2H_4). The degradation of the transformer oil results in H-O and C=O bonds hence the presence of above gases. Also aromatics compound, carboxylic acids and presence of water. In case of the thermal degradation it is found that the degradation does not take place up to 150˚C and there is not much absorption in the transformer oil with copper or with Kraft paper which shows that there is very slight change in the transformer oil. Also with the increase in the degradation of the transformer oil the transmittance decreases and the absorption increases.

The UV spectrometry technique is used in this study for the detection of the interpretation of the contamination level for the transformer oil. The deformation of the aged transformer oil significantly changes its absorption spectrum. The absorption in transformer oil infers about the presence of aromatic compounds in it. There is shifting in the absorption peaks with the degradation in the transformer oil. In case of thermal degradation, there is not much changes in the transformer oil up to 150˚C temperature. Transformer oil experience very large amount of heat in the practical life, so at this temperature there exist very small amount of change in the oil. Absorption spectrum also says about the insulation system condition due to normal as well as accelerated ageing. Also extension of life is possible leading to proper asset management and good capital investment can be achieved.

5.2 SCOPE OF FUTURE WORK

In the present study changes in oil has been studied under accelerated thermal stresses. A study of this kind is helpful in identifying the most sensitive properties with respect to ageing. Eventually, this knowledge data base will also be helpful in evolving a condition monitoring strategy for actual transformers.

The present and the current research have thrown a few interesting problems in further research could be undertaken, these problems are outlined below:

- Prediction of gases and fault occurred through DGA, NMR and HPLC.
- Expert systems have to be developed that give an alarm signal to system operators. Frequency response Analysis along with specialized software may be developed to assess the displacement inside the transformer.
- To develop Artificial Intelligence (AI) software to diagnose transformer faults.

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