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Reclamation of Aged Oil Using Physical-Chemical Method and Analysed Using ANFIS Algorithm

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Abstract : *In this work, the transformer oil reclamation experimental test has been created utilising the physical-chemical reclamation technique and oil lifespan analysis using ANFIS algorithm. The significant of work is that it develops an ANFIS algorithm for estimating transformer life and analyzing transformer oil reliability. Rubber seed oil (mineral oil) is used in transformers to cool the substantial portion of the power transformer and decrease electrical ageing issues. These mineral oils interact chemically with the windings, suffering electrical and mechanical pressure owing to high temperatures over its power balance which leads to moisture and oxidation. In order to improve the performance of ageing oil, a physical and chemical reclamation approach with two primary steps, Coagulation and Adsorption, is used. Breakdown voltage, flash point, viscosity, and fire point are the important dielectric qualities of oil reclamation that will differentiate the performance between before and after reclamation when compared to diverse oil samples. The results of the work revealed that the physical-chemical reclamation process is enhanced the dielectric characteristics of the ageing oil, and the parameters of the reclaimed oil are utilised to predict the projected lifespan of the transformer service.*

Keywords: *power transformer, rubber seed oil, physical-chemical method, oil reclamation, Parzen window function*

Introduction

In transformer, oil serves as a protective interlayer to minimize deterioration of the metallic surface as well as electrical isolation between the different live sections. Improving thermal dissipation is one of the key roles of transformer oil. Because of certain power losses during operating condition, transformer cores and its field winding become hot. Oil transfers heat from the core and windings to the surrounding tank, where it is eventually dissipated out to the environment. Transformers produce a lot of heat, which must be extinguished to prevent the copper from melting and the failure of the entire transformer. The life of the power transformer life is depending on the insulating medium. Different types of oils, including mineral oil, chemical oil, typical oil, and silicone oils, are used in transformers. One of those insulators is mineral oil, which is used for transformers and other high-voltage equipment. Although this mineral oil has excellent electrical and cooling properties, it is derived from mining resources, making it a non-renewable resource which is difficult to biodegrade. However, the presence of polynuclear aromatic hydrocarbons in this mineral oil makes it hazardous as well [2]. Thus, if transformer oil leaks, catches fire, or explodes, the surroundings may become hazardous. Due to the aforementioned drawback, several studies were done to develop a cleaner and effective oil insulation to replace mineral oil.

The distribution transformer has been used with vegetable oil that has been derived from sun floral, olives, rapeseed, and groundnuts etc., according to a variety of literature [1, 3- 6]. Vegetable oil, which is a type of natural ester, degrades over time and is therefore eco-friendly. Additionally, compared to mineral oil, vegetable oil offers superior electrical characteristics, such as a greater electrical insulation and permittivity [7]. The resistivity of vegetable oil is virtually as high as that of mineral oil, according to other electrical properties [8]. Additionally, vegetable oil has a greater flash point and fire point, which

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lessens the likelihood of a fire. The prospect of using rubber seed as the source of the ester oil for oil insulation was explored in this work. Because the rubber oil is more advance than the other type of oils, which is used for cooling the transformer equipment's and insulating the oil. The transformer oil has good electrical power for insulating the transformer.

Moreover, the transformer consists of paper, oil and other cellulose solids. In the insulating part the paper is used to insulate the transformer windings, cellulose solids the mineral based oil is used [1]. The transformer may operate at higher temperature so, the oils must be control for more prominent security. Transformer oil that gives great effectiveness in the genuine field of activities [2]. Laboratory and field have shown that the transformer oil contains 70 % of diagnostic information and also the oil analysis is used to monitor the transformer conditions. Based on this, the oil was reclaimed frequently through the filtration and removes the impurities. Because the transformers equipment's are mainly affected by the oil degradation. The transformer oil will be affected by electrical stress, overheating, oxidation and contamination, etc. The Moisture generates electric pressure in the presence of oxygen in oil and heat. Based on this value the acid product value increases the oil degradation in the mineral oil [5, 6].

The transformer oil contamination is reclaimed by using various methods based on water, oxidation, and adsorption process. It will damage the insulating part of the system. Therefore, the most proper reclamation methods are used to control the transformer age oil, also to recover and purify the rubber seed oil [7]. The bauxite method used for oil reclamation, but in this process the generated waste values are discarded in the landfill sites [8]. The palm shell active carbon method is used for oil reclamation, it will reclaim the water, decrease gas from the oil gas and air purification etc. This method the reduce number of reclamation cycle and also remove the relative content of first reclamation cycle [3]. The active bentonite is used for deterioration oil regeneration process using sulphuric acid for improve the adsorption power and the distilled water is used to washed until the acid was removed. The vegetable oil is also used in the removal of the oil using active carbon, it is instead of the mineral oil. In bentonite method the vegetable oil also used to increase the breakdown voltage and the viscosity of aged transformer oil, but the oil fire point and flash point values are reduced, so the aged oil value also not purified clearly [9, 10]. The traditional oil provides alternate use of transformer oil to remove the aged oil and avoid the natural impact [11]. The oil reclamation processes carried by using clay and activated carbon, this method can remove the oil deterioration such as metals, acids and sludge. But this method will decrease the natural inhibitor in the oil. To overcome this problem the fresh transformer oil maintain the oil range from 0.26 to 0.37 %.the percentage values are calculated by using ASTM [12].

Bentonite method has been used to absorb the metal ions and remove the Nanoparticles from the aged oil or waste water. The mineral clay contains the octahedral sheet, it is placed inside the tetrahedral sheets. This minerals are remove the various exchangeable and impurities of the age oil. But the bentonite is modified by using acid [13]. The anti-oxidation method is more advanced than the previous method. It is used to purify the oil contamination and regenerate the mineral oil. But this method will operate only in the mineral oils. This method also used to reclaim the waste oil. This method will act with the fuller earth (clay) for oil reclamation process [14]. The fuzzy method is used to estimate the age of the transformer equipment, the transformer age is measured by the inputs parameters such as interfacial tension number of the transformer, and acid number, then the remnant age of the transformer service is an output. In this method the values are not measured clearly [15]. The transformer oil reclamation process contains three methods such as chemical, physical and physical-chemical method. The chemical oil reclamation method will use sulphuric acid and alkali. It is commonly remove the oxygen compound and tar from the oil. It reclamation treatment contain two layer, the first layer has hydrocarbon and acid and the next layer has acid tar. The main drawback of this method is that this method doesn't remove highly toxic chlorine and polycyclic arenes. The physical method contains separation, settling, and filtration. Normally the physical method will remove oily sand, metal, dust, and remove the nanoparticles in the water. It will not alter any chemical structure in the transformer oil. So the fuzzy don't fully reclaim the aged transformer oil. Due to the excellent accuracy of the support vector machine (SVM) and genetic algorithm (GA) combination, transformer failure diagnosis in [16]. A novel

technique for determining the amount of water in transformer oil is to use multi-frequency ultrasonic waves in combination with a back-propagation neural network that has been enhanced using principal component analysis and genetic algorithms are discussed in [17]. In [18] a grey relational analysis (GRA) approach is used to pick the best mixed liquid insulation and to identify the best sample concentration. In this work [19] feed forward neural network (FFNN) trained using quasi-Newton and conjugate gradient learning techniques, the breakdown voltage of liquid insulation was changed, and its inter-relationship was revealed. Nowadays various algorithms are used for several applications to enhance their performance discussed in [20, 21]. Further investigation from the literatures has found that no reclamation study for the aged oil employing the ANFIS approach has been accomplished. We have made the effort to investigate the physical-chemical technique and use an optimization strategy to examine the performance needs of aged transformer oil.

Hence this work proposed the ANFIS algorithm for dissolved gas analysis to determine the life span of oil which is a good trade between fuzzy and neural system. This is due to the smooth nature of the microscopic network and obscure control. This algorithm is successfully used for life estimation of transformer and use more number of membership functions in their operation such as triangular membership function, trapezoidal function, and Gaussian membership functions. These functions will control many parameters, for example Gaussian shape control only 2 parameters and pi-shape control 5 parameters. Therefore the parzen window membership function is used for oil dissolved gas operation and life estimation of the transformer. This parzen window membership function will control only one parameters. The work investigates the reclaim the oil deterioration from the aged oil and estimate the life of the reclaimed oil used in the transformer. The reclamation is performed by physical-chemical reclamation method and also investigates the dissolved gases and lifespan of the power transformer using ANFIS algorithm in parzen window membership function. The main objective of the work is to examine the use of vegetable oil as transformer oil using reclamation method

The paper is organized as follows; in section 1 explains the introduction, motive and contribution of the work, methodology of proposed work in section 2. In section 3 the proposed algorithm is elucidated and experimental setup is discussed in section 4. Finally the results and discussion is illustrated in section 5.

Methodology

Transformer life / aged oil deficiency is a factor in promoting tropical paper, and it is accompanied by distortion. The transformer decomposition is occurring by electrical surges, vibration, stressful events. The transformer has number of process that affects the mineral oil and insulating papers. If the transformer paper and oil are failed the total transformer also failed. Here we focus about the rubber seed oil reclamation in transformer using physical-chemical reclamation method. The physical-chemical reclamation method process for oil reclamation treatment. The oil reclamation is divided in to two main processes such as coagulation and adsorption. The coagulation techniques are used for waste oil treatment. It will make the aged oil in to gel format, this reclaimed oil containing colloids and metal ions. The adsorption process is an adhesion of ions, gas, molecules and atom. It is used to purify the aged transformer oil. The adsorption contains some type of properties are used for oil reclamation process such as silica, bleaching clays, and aluminium oxide etc. These properties are very expensive and artificial. The transformer oil is easily affected by the moisture contamination (water). This contamination is removed by using the coagulation technique, it will decrease the water emulsified from the oil. Oxidation is the process, when the oil molecules are reacting with the oxygen molecules. The oxidation deterioration is also occurred by the moisture mechanism, so the oxidation deterioration is more powerful than the moisture deterioration. The speed of the oxidation is depends on the mineral oil temperature. When the oil rotating speed increase the oxidation is also increase, the oil sludge level also increased. Therefore the oxygen must be removed from the mineral oil. Therefore adsorption techniques are used to remove the oxidation from the rubber seed oil.

Physical-chemical reclamation method

The performance of the physical-chemical reclamation method is more advance than other type of oil reclamation methods. The importance of this method contains the chemical and physical reclamation functions. The main use of the physical-chemical reclamation techniques is to improve the oil reclamation and paper insulation. Before reclamation process the mineral oil was cleaned by using some techniques are shown in below,

Gravitational cleaning: The gravitational cleaning method is a simple method. It is used to eliminate the water micro droplets contaminations from the rubber seed oil. The rate of the waste particles is depending on the size of the impurities, density and viscosity of the oil and deposition substance, and the height of the oil column. The temperature condition of the oil is increased based on the deposition rate of the oil. If the oil temperature is increased above 90^{o}C the oil begins to boil [22].

Magnetic field: In the transformer oil the solid particles are removed by using magnetic field technology. The permanent electromagnets will generate the ferromagnetic particles [23].

Vibration cleaning: The vibration cleaning method will remove the minute particles from the mineral oil which is used for oil purification. After vibration cleaning the oil reclamation is performed by some oil purification techniques such as adsorption, and coagulation. These techniques are mainly used to remove the oil contaminations [24]. The block diagram of physical -chemical reclamation techniques are given below,

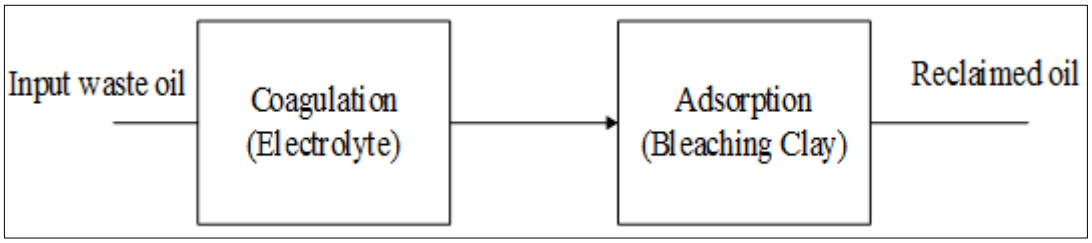


Figure 1. Block diagram of physical-chemical reclamation method

Coagulation

Coagulation techniques are used to minimize the pollution from aging oil. It contain some basic steps such as first the electrolyte is added to the oil, then cool the oil and pass the electric current to the oil finally use the radial energy to the oil. The output of the reclaimed oil is placed in the colloidal state. The benefit of these techniques is to eliminate the moisture (water) droplet from the aged oil [25].

Adsorption

Adsorption used to pass the oil through a special absorbent layer is knows as percolation. Because the aging product consists of undesirable contaminants. The silica gel, bleaching clay, alumina oxide and zeolite are substance used for oil absorbent. Here the clay is also used to minimizing the oil reclamation; the process is also called “fuller earth” [25, 26].

ANFIS (Adaptive Neuro Fuzzy Interference System)

Adaptive Nurse Fuzzy Interrupt System (ANFIS) [27] is a synthetic neural network and clear logic policy. This algorithm is used to predict the lifespan for transformer oil. This algorithm is an effective technique to generate the relationship between the output and input data. These algorithms have parzen window membership function for controlling the parameters. The ANIFS has number of inputs but it has only one output. The ANIFS algorithm functions are perform in Takagi-sugeno model. The rules of this model is given below,

Rule 1: if x is A1 and y is B1, Then $f1 = p_1 x + q_1 y + r_1$

Rule 2: if x is A2 and y is B2, Then $f2 = p_2 x + q_2 y + r_2$

where A1, A2 and B1, B2 are the membership function of x and y, and p1, q1, r1 and p2, q2, r2 are the linear parameter in the If -Then function. The architecture of this algorithm are shown below,

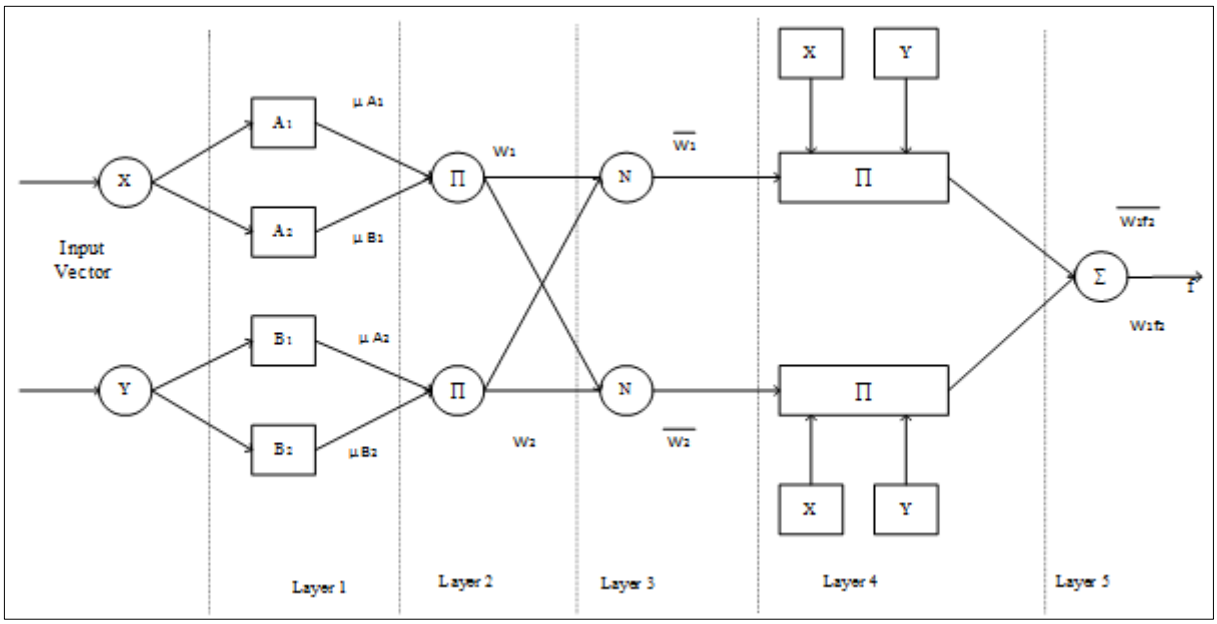


Figure 2. Architecture of ANFIS Algorithm

This algorithm consist of five layers, [28] which the circle indicate the fixed nodes in the layer and the square indicate an adaptive node. The first layers are full of adaptive terminals, and this layer output is indicated,

$$O_i^1 = \mu_{Ai}(x), i = 1,2 \quad (1)$$

$$O_i^1 i = \mu_{Bi-2}(y), i = 3,4 \quad (2)$$

The second layer is fully cover by fixed nodes, the nodes are performed at the simple multiplier and the fixed nodes are labelled with M. the output of this layer is represented by

$$O_{2i} = W_i = \mu_{Ai}(x).\mu_{Bi}(y), \ i = 1, 2 \quad (3)$$

The third layer also covered with fixed node, but it is labelled with N, the result of this layer is denoted by

$$O_{3i} = W_{i^-} = \frac{W_i}{\sum_i W_i}, i = 1,2 \quad (4)$$

The fourth layer has fully adaptive terminals, with its result is simply merely firing power. The result of this layer is denoted by

$$O_{4i} = \overline{W}_i f_i = \overline{W}_i (p_i x + q_i y + r_i), i = 1,2 \quad (5)$$

The next layer is a last layer in the ANFIS algorithm, it has one fixed layer, this fixed node is labelled by S. Below is the node processor, the addition of input signals and its output

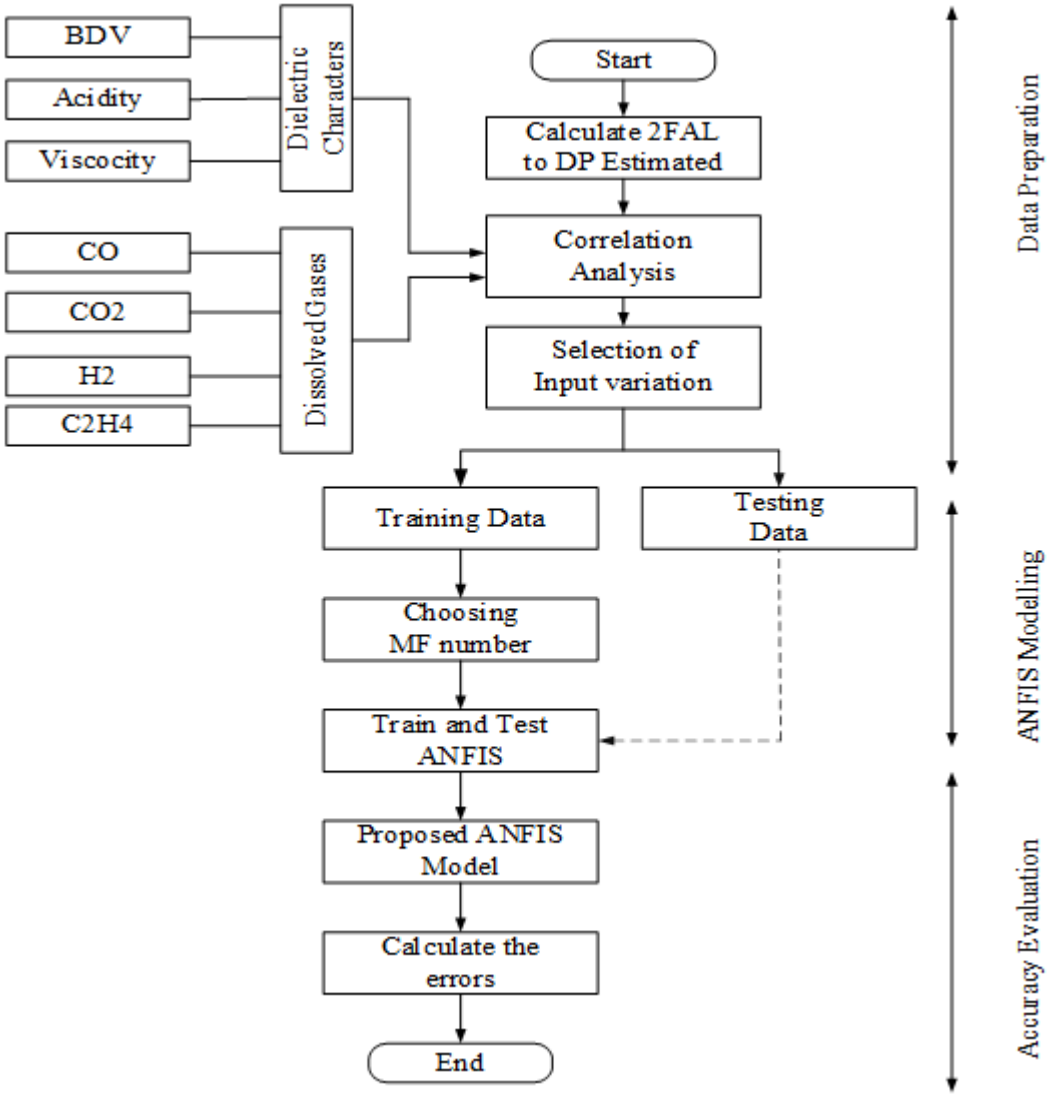
$$O_i^5 = \sum_{i=1}^{2} \overline{W_i} f_i = \frac{(\sum_{i=1}^{2} W_i f_i)}{W_1 + W_2} \quad (6)$$

This algorithm contain two adaptive layers in the architecture, namely layer one and layer two. It contains two main operations such as backward and forward path function. The front line of the layer 1 parameter has been fixed and the layer 4 is the resulting parameter, which is a recursive perimeter square assessor (RLSE). The backward path operation are totally opposite then the forward path, here the consequent layer is a fixed parameter and the gradient descent updates the premises parameters in layer 1. The error of this algorithm is indicated by the variation between the actual output and the output required, and the spread comes back to the first layer. In the ANFIS algorithm, hybrid techniques are used to improve the parameters of trained data. The input function of this algorithm is in parzen window membership function. The result of the algorithm is always constant. Finally the output of the algorithm is written as

$$f = \frac{w_1}{w_1 + w_2} f_2 + \frac{w_2}{w_1 + w_2} f_2 \tag{7}$$

The hybrid method will combine both the forward and backward paths. The hybrid method is more powerful in the ANFIS algorithm, because it generate the clear output without any error.

Flow chart of ANFIS algorithm



The ANIFIS algorithm contains three stage of testing process such as Data preparation, ANFIS Modelling, and Accuracy evaluation.

Data preparation (DP)

The DP value is taken from the 2FAL (Furfural Compound). The correlation of estimated DP consists of, dissolved gases and the dielectric characteristics of transformer oil are analysed. The combination of two input variables for predicting the DP is selected. The three sample is divided into training and testing process. The degree polarization is calculated by using furanic compound, which is directly combined to the DP. The furfural compound also used to measure the value of DP. The DP measured equation is given below

$$\mathrm{DP} = \frac{Log_{10}(2FAL_{ppm}) - 1.51}{-0.0035} \tag{8}$$

The output of data preparation stage is send to the ANFIS model stage. It is used to calculate the energy power resource limit (Eprl).

3.3. ANFIS modelling

The output of the data preparation is used to build the ANFIS model and choose the membership function. The parzen window membership function is used to calculate the correct combination for life estimation.

3.3.1. Accuracye evaluation

The accuracy evaluation is used to calculate the testing process values and find the lifespan of the power transformer.

The percentage of the estimation life is measured by using (% Eprl) equation

$$\%\mathrm{Eprl} = 100\text{-}\left\{\frac{\left[Log_{10}(DP) - 2.903\right]}{-0.00602}\right\} \tag{9}$$

Then the age of the transformer service is measured by

$$\frac{1}{DP_t} - \frac{1}{DP_0} = A.e^{-\frac{Ea}{RT}}.t \tag{10}$$

3.3.2. Parzen window membership function

The Parzen window membership function approach was introduced by Emanuel Parzen in 1962. To enhance ANFIS functionality, Parzen Windows Distribution has been included as a new membership function. Lowering consumption time, improving the process to reflect real-time application, and reducing the Root Mean Square Error (RMSE) between real and forecasted data are all ways to improve processes. The function produce a mathematical analysis and also different applications and domains, such as classification of the gas and pattern recognition.

The general equation of non-parametric density estimation is:

$$p(x) \cong \frac{K}{VN} \tag{11}$$

where N is a volume surrounding of x, the value of V is fix and the K value is find from the data, this function lead to Kernel Density Estimation (KDF).

The total value of k samples is fall in the region R, out of n, is measured by

$$K = \sum_{i=1}^{n} \phi\left(\frac{xi - x}{h}\right) \tag{12}$$

The probability density estimation of the parzen for dimensional is estimated by

$$P(x) = \frac{k/n}{V} = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{h^2}\phi\left(\frac{xi - x}{h}\right) \tag{13}$$

This equation the $\phi\left(\frac{xi - x}{h}\right)$ is called as window function.

The last equation of the parzen window membership function is used for ANFIS algorithm is given below

$$f(x,h) = \exp\left(-\frac{1}{2}\left(\frac{x - xi}{h}\right)^2\right) \tag{14}$$

The main advantage of this membership function is to reduce number of parameters compare to the other type of membership function and it can operate any kind of normal mixtures.

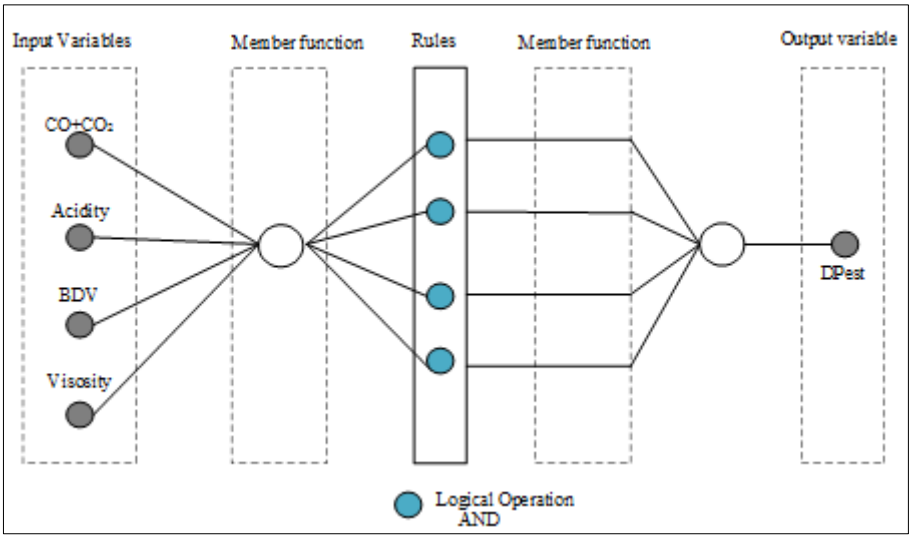


Figure 3. Function of ANFIS Algorithm

2. Materials and methods

In this section describes how the aged oil reclamation experiment was done and summarizes the data taken. Equipment and explorations used in this section are generally described the procedure followed to collect the data.

2.1. Sample preparation

The sample oil preparation is followed by the IS: 1866:2010 standards. Use rubber seed oil to prepare samples in the work. The testing cell contains the oil samples. The sample fluids have completely filled the cell. It will distinguish between oil components and oil that is put through testing. Based on the voltage breakdown in the testing cell, the oil will be put to the test. Three oil samples will differ from the tested oil. The oil sample preparation process is explained in figure.

Figure 4. Voltage breakdown during sample oil testing

2.2. Reclamation process

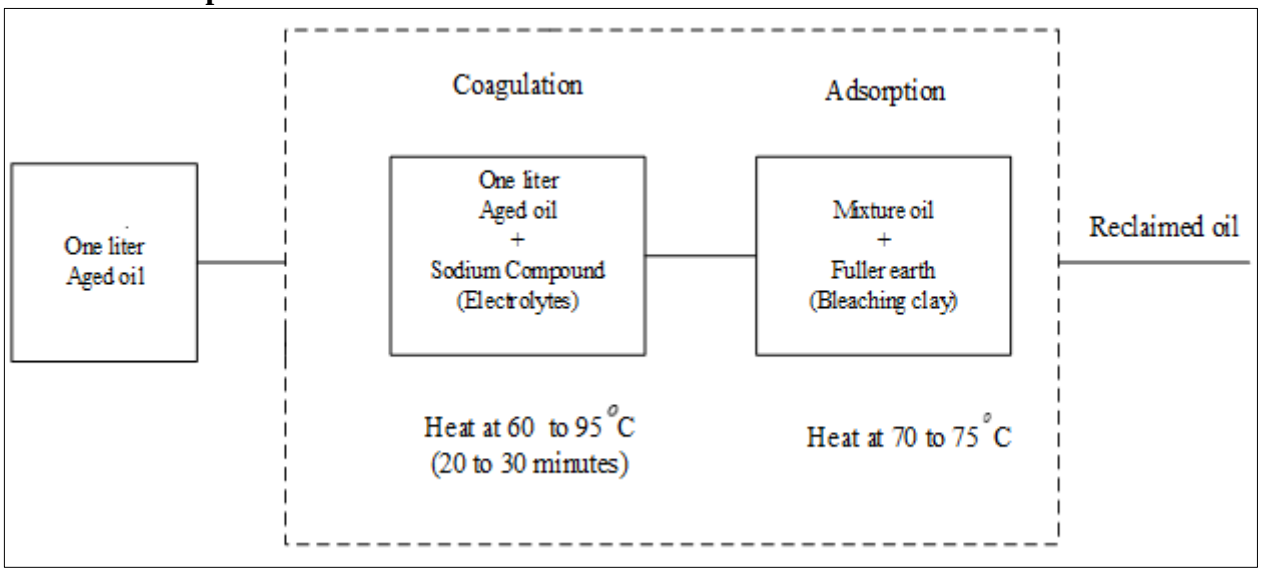


Figure 5. The block diagram of reclamation process method

The reclamation process is used to develop the strength and dissolution factor of the aged oil. The aged mineral oil regeneration process is performed by using physical-chemical reclamation method. This reclamation process contains 225 voltage, and the temperature of the oil testing is 27ºC. The one litter aged oil is given in to reclamation method. It contains two main stages such as coagulation and adsorption. The first stage the aged oil is added with the sodium compound (electrolytes). This oil mixture is heat at 60 to 95ºC, and the oil mixture agitated takes for 20 to 30 min. The heat must be maintained constant during the process period. Then second adsorption stage, the mixture oil will add the fuller earth (Bleaching clay). The mixture is heats at 70 to 75ºC temperatures. Finally the reclamation method gives the pure mineral oil output.

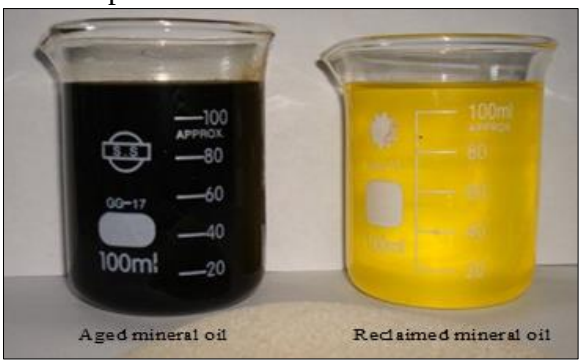


Figure 6. Colour variation of the mineral oil before and after reclamation process

2.3. Performance measurement

The measurements obtain from the reclamation process are discussed in this section. The oil testing and measurement are based on three types of sample oils. The sample oil measurement is centred on the breakdown voltage, moisture content, resistivity, acidity, flash point, and kinematic viscosity.

2.3.1. Physical appearance of oil samples

This testing process contains three sample oils, they are named as sample A, sample B, and sample C. The oils sample is observed by the colour difference of the oil. The colour of the first sample oil is pale yellow, the sample oil is yellow colour and the third sample oil is bright yellow. The figure shows the physical image of the oil sample in different colours.

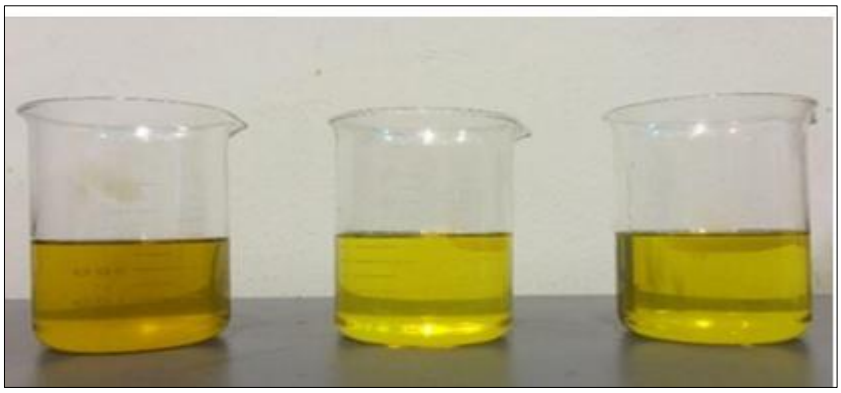


Figure 7. Physical appearance of three sampled oil

2.3.2. Breakdown voltage

Breakout voltage (BDV) is also called dielectric break voltage test, the BDV test provides insulating fluid. The sample oils are placed in the testing cups, and test in the room temperature of 2^{o}C. The voltage is applied after the air bubbles remove from the oil sample. By using the control knob the voltage values are varied, and measure the BDV values for every sample oil. This measurement shows the sample A has high BDV value, which is 53.2 KV while compare to the other sample oils.

2.3.3. Moisture content

The sample oils moisture content is measured by using Karl Fisher. This technique also calculates the mean value of the sample oil. The water content has high moisture content (1,210.60 ppm). In this testing process the sample oil A has low the moisture content (15.3 ppm). Because the sample A is an insulating oil.

2.3.4. Resistivity

The resistivity is use to oppose the strong electric current in the transformer oil. Here the resistivity value of the sample oils are observed based on dissolved impurities the oil temperature. This measurement shows the sample oil A has 121 values.

2.3.5. Acidity

The sample oils must have low acidity value, because it will determine the age of the oil. By using this acidity value the mean value of the sample oil is measured. This acidity values are used to estimate the reclaimed oil condition. In this sample measurement the sample A has low acidity value (0.021) then the other sample oils.

2.3.6. Flash point

This point is an important parameter in oil testing and reclamation, it used to find the tendency of the mineral oil to form flammable mixture with air under laboratory conditions. This point also used in

safety regulation and shipping to define the combustible material and flammable. Flash point pressure is measured by ASTM.The flash point indicate the volatile in non-flammable or non-volatile materials. The Panosky Martin method is used to measure the value of the flash point from the oil. The testing process is performing only in room temperature. The sample oil is filled in the test cup, the temperature of the oil is increased by the energy regulator. During that period the flash point will measured. In this testing process the oil sample A has high point, which is 150^{o}C.

2.3.7. Kinematic viscosity

The viscosity range of the operating temperature is very important in the transformer oil, because it can collision in both internal components and cooling part. These parameters also measure resistance to fluid due to electrical pressure. The sample oil viscosity is measured only at 40^{o}C. The viscosity factors will determine the fluid resistance and sample temperature of oil. If the temperature of viscosity is increased the oil efficiency and load are goes to negative effect, so the viscosity value is essential to control in the oil transformer service. In this testing the sample A has low viscosity value. The values of other sample oils are higher than the sample oil A.

2.3.8. Dissolved gases analysis

The Dissolved Gases (DGA**)** is a most of the important effective tool for monitoring the service of the transformer and avoids the failures of transformer equipment's. These dissolved gases are formed by the some factors such as partial discharge, corona, arcing, and high temperatures. Mainly the transformer fault is divided in to three types, such as low energy discharge, high energy discharge, and overheating.

The dissolved gases are measured by using ANFIS algorithm in parzen window membership function. This algorithm will measure some dissolved gases such as Methane (C_4H), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2), and Hydrogen (H_2) etc.

The value of dielectric properties and dissolved gases of the reclaimed transformer oil are used to estimate the age of the transformer service.

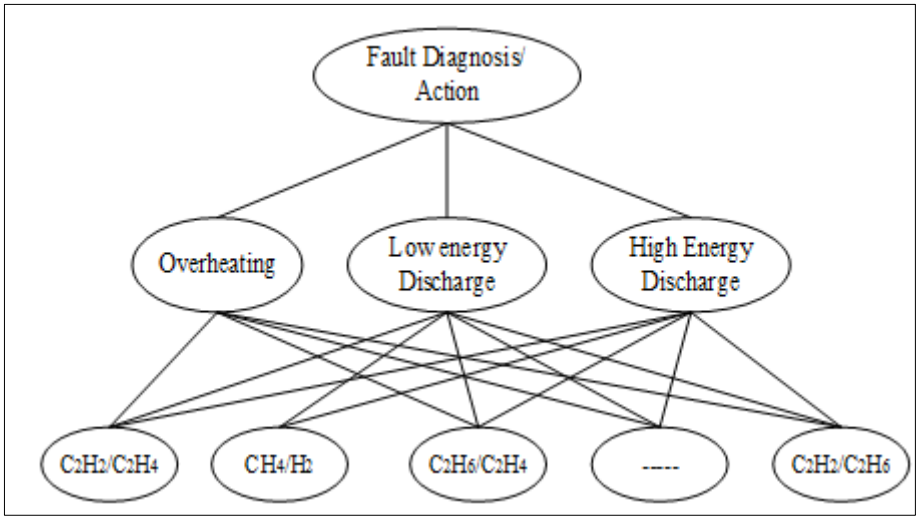


Figure 8. Diagram of dissolved gases fault

Table 1. Testing parameters and testing equipment's

S. No	Testing Parameters	Testing Equipment's
1	Breakdown Voltage (BDV)	IS:6792-2013 50HZ ± 2HZ
2	Moisture Content	IS:13567-2013 Karl Fisher Titration Method 230 10V

3	Resistivity	IS:6103-2011 three terminal cell 250Vrms\mm.
4	Acidity	IS:1448(P:2)-2013
5	Flash point	IS:1448(P:2012 Pensky Martens Method
6	Kinematic Viscosity	IS:1448 (P:25)-2013
7	Dissolved gas	IS:10593:2011&9434-2013

3. Result and discussions

To demonstrate and evaluate the performance of the reclamation method, mainly applied to reclaim the aged transformer oil and estimate the lifespan of the transformer oil. The oil reclamation is performed by physical-chemical reclamation method and the lifespan is calculated by parzen window membership function, this function is obtained from the ANFIS algorithm.

Table 2. Testing parameters of different oil samples A, B, C

S.No	Testing Parameters	Sample A (Pale Yellow)	Sample B (Yellow)	Sample C (Bright Yellow)
1	Breakdown Voltage (kV)	53.2	52.1	41.2
2	Moisture Content	15.3 ppm	18.4 ppm	22.6 ppm
3	Resistivity	$121x10^{12}$ Ω-cm	$81x10^{12}$ Ω-cm	$47.1x10^{12}$ Ω-cm
4	Acidity	0.021 mg-KOH/g	0.042mg-KOH/g	0.081mg-KOH/g
5	Flash point	156°C	152°C	148°C
6	Kinematic Viscosity	14.38 cSt	14.38 cSt	16.71 cSt
7	Dissolved gas	4.7%	6.7%	9.7%

The dielectric strength of sample oil is tested and compared transformer oil which is demonstrated in the below diagram.

In Figure 9 demonstrates the quality of oil when 50 kV voltage is connected. From the diagram, we can be seen that RSO has the most high-quality esteem, which is 13840.30 kV/mm when 0.2 cm hole is connected. It is denoted in yellow color.

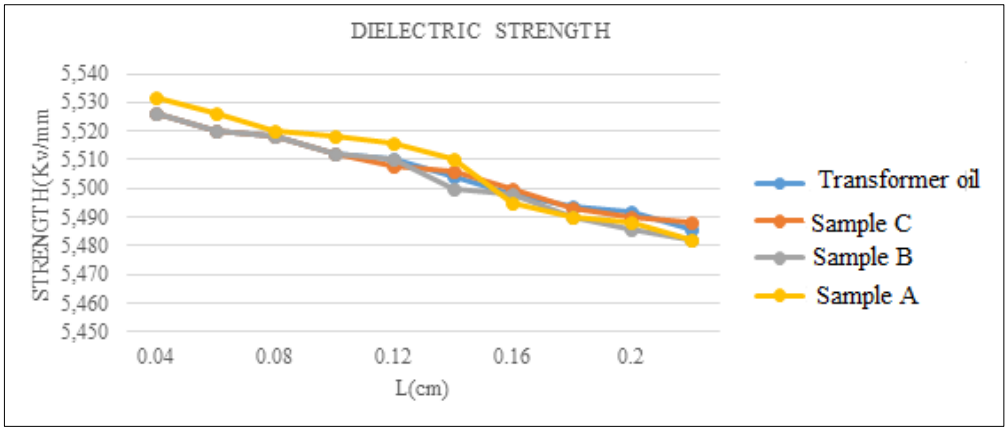


Figure 9. The Strength of oil at 20 KV

In Figure 10, when a 100kV voltage is applied, sample A oil shows the highest strength when the gap of the electrode is 0.2 cm. Overall, the dielectric strengths of oil decrease as the gap of electrode increases; and within controlled moisture level, shows comparable dielectric strength to mineral oil.

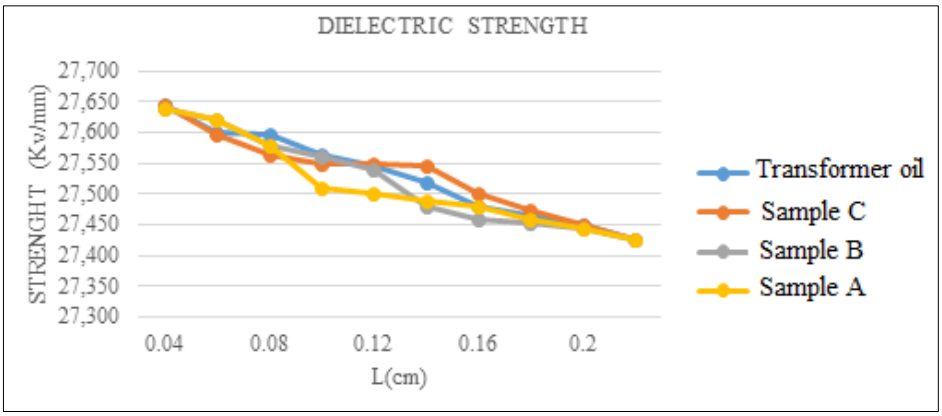


Figure 10. The Strength of oil at 100 KV

3.1 Breakdown voltage (BDV)

This parameter is most important and this value is usually first investigated in the testing process. The BDV should be held at highest level than other sample oils. If the BDV level is low, it indicates the moisture content growth of the rubber seed oil. The breakdown voltage of the reclaimed oil is measured by standard testing equipment IS: 6792-2013 50HZ ± 2HZ. The Table 2 shows the variation of breakdown voltage between the sample oils and reclaimed oil. These voltages is measured at normal room pressure and temperature. The value of sample oil A is higher than the other type of samples oil.

3.2 Moisture content

The moisture content is generated over 80^{o}C from the oil deterioration. The hydrogen and carbon monoxide are generated the temperature of the oil is increased over 120^{o}C. The moisture content values are measured by using Karl Fisher (IS: 13567-2013). The reclaimed oil sample values is decreased from the aged oil.

3.3 Resistivity

The Table 2 indicates the power of oil process on the resistance of sample oils. The value of the resistivity is calculated by the inequality of filtration effects and heat of oil reorganization. Finally the resistivity value is measured by using IS: 6103-2011 three terminal cell. The result of this testing process shows that the sample oil A has high resistivity than the other type of oil samples.

3.4 Acidity

The acidity value of this testing process is measured by using standard equipment IS: 1448(P: 2)-2013. The acidity value of the sample oils are shown in the table. The acidity value of the reclaimed sample oil A has low value, which is 0.021. This acid value is used to determine when the oil is changed.

3.5 Flash point

The testing value of flash point is given in the Table 2. The flash point of this testing process is measured by using Pensky Martens Method IS: 1448(P: 2012). The flash point of the reclaimed sample oil A has 156^{o}C. This oil is treated with physical-chemical reclamation process.

33.6 Kinematic viscosity

The Kinematic viscosity value is measured by using viscometer (IS: 1448 (P: 25)-2013). The table shows the viscosity variation between the sample oils. The viscosity and pressure is measured at the room temperature (27^{o}C). The measurement shows that the sample A has low viscosity than the other type of sample oils.

3.7 Dissolved gases analysis

The dissolved gas of the oil is an important role in the transformer oil reclamation process. There is a limit for every gas present in the mineral oil. The gases of the reclaimed oil and the sample oils are analysed by IS: 10593:2011&9434-2013 and the results are shown in the Table 2. The testing gases and its values are shown in Table 3.

Table 3. Analysis of gas in the sample oil testing process

S. No	Gases	Sample A	Sample B	Sample C
1	Methane	ND	1 ppm	10 ppm
2	Ethylene	ND	ND	5 ppm
3	Ethane	ND	ND	15 ppm
4	Acetylene	ND	ND	ND
5	Carbon monoxide	16 ppm	29 ppm	101 ppm
6	Carbon di-oxide	202 ppm	324 ppm	1935 ppm
7	Hydrogen	ND	ND	2 ppm
8	Total gas content	4.7%	6.7%	9.7%

These dissolved gases are measured by using parzen window membership function in the ANFIS algorithm. In this testing process the sample A has lower dissolved gases then the sample B, and C. the total gas content in the sample A is 4.7%.

3.8. Expected life estimation of the transformer

The four alternator samples are used to estimate the expected life of the transformer is shown in the Table 2. The dielectric properties and the data of the dissolved gases are used to predict the status of the transformer based on the degree polymerization. These predicted dielectric properties are used to expect the life period of the transformer by using the equation 8. The result of the lifespan calculation is shown in the Table 4.

Table 4. Life estimation of transformer with different sample combination

Sample	Running time	Dielectric Properties Predicted (ANFIS)	%Eprl	Expected life Estimation (year)
Sample A	25 Y	59.86	80 %	8.8
Sample B	21 Y	476.87	79%	8.1
Sample C	20 Y	369	42%	5.6

4. Conclusions

In this investigation, the experimental test have been established the transformer oil reclamation and analysis the lifespan of oil by using physical-chemical reclamation method and ANFIS algorithm. Moreover, the reclamation method is a proven technic for the oil purification and removes the moisture and oxidation. As a source of vegetable oil, the inedible rubber seed oil (RSO) has a strong prospect and may be used to create oil insulation. The rubber oil testing process shows the great electrical properties such as low acidity (0.021 mg-KOH/g), high breakdown voltage (53 kV), high flash point (156^{o}C), and low viscosity (14.38 cSt). Among three samples, reclaimed rubber seed oil of sample A had the highest breakdown voltage, indicating that it has a better possibility to become an oil insulator. The Adaptive Neuro Fuzzy Interference System algorithm using parzen window membership function is used to measure the dissolved gases. By utilising the ANFIS method, the life of oil is projected to be 8.8 years for a sample A outperforms other samples of oils in terms of performance.The results of dissolved gases and the dielectric properties of rubber seed oil shows better performance than existing methods which are used to estimate the lifespan of the transformer service.

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