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Improvement of Used Transformer Oils with Activated Bentonite

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Abstract

This research presents the evaluation of activated Bentonite material for treatment of used transformer oil. Different properties such as; electrical, physical, chemical and thermal of used transformer oil were measured before and after purification and treatment. Two power transformers were used in this research (6.4: 4.6 MVA, 3 phases, 50 Hz). One of them was filled with purified oil and the other was filled with activated Bentonite treated oil after purification, and then the two power transformers were tested for one year under practical conditions of the operating field. Initial tests have indicated that the use of Activated BENTONITE in the treatment process for the aged transformer oil improved breakdown voltage, water content, total acidity and flash point. Thus activated Bentonite gives an ideal treatment of aged transformer oil with its environmental and economic advantages. Moreover, activated Bentonite is available at many places in Egypt with low costs.

Keywords: Aged Transformer Oil, Bentonite, Breakdown Voltage, Physical and Thermal Properties

1. Introduction

Transformer oil plays very important roles in the power transformer as insulation and heat transfer medium, many researches and studies have been reported and examined for decades to understand its electrical, physical and molecular characteristics, behavior under certain condition such as high temperature, techniques to procure the best transformer oils, and so forth [1-3].

Increasing awareness of the environment and the need to limit the impact of human activity gives a clear impetus to replace conventional insulating oils in high voltage plant with environmentally friendly alternatives. In addition, oil leakage from equipment is a serious concern, both in terms of the clear up operation and equipment replacement costs.

The insulation system in transformers can be improved, compared to mineral oil, using new high grade dielectric fluids like Envirotemp FR3 [4-6].

Oil immersed distribution transformers can be built with very low losses compared to dry-type transformers. This fact is well known because oil is a better cooling and insulation medium than air. The active part, core-and winding-design will be smaller in oil, *i.e.*, lower material consumption and lower losses.

Transformer oil acts as a cooling and insulating medium in transformers. This insulating oil not only fills up the pores in the fibrous insulation such as paper, but also the gaps between the turns of the winding and the spacing between the winding and the tank. The oil, in addition to functioning as a dielectric also serves as a cooling medium.

Traditionally, mineral oil, synthetic esters and silicon oils have been used in transformers. More recently, the environmentally friendly sunflower oil has been used as transformer oil for special purposes [7-10].

The life time assessment and evaluation of the condition of a transformer is of high importance for the users and manufacturers. The end of life of the transformer is defined as the decrease in the tensile strength of the isolating paper to approx 50% of the starting value [11-15].

The insulation system in a power transformer degrades under normal operating conditions, in particular with higher temperature, higher moisture and oxidation. The remnant life of a transformer is significantly influenced by the condition of solid insulation. Currently, degrada-

tion of insulation in a transformer is monitored by sampling the oil and analyzing for dissolved gases, furan content and by examining the change in the degree of polymerization (DP) of cellulosic paper. In current deregulated electricity markets, non-destructive diagnostic techniques are becoming more and more popular for condition-based maintenance of aged transformers.

In this research tested samples were taken from transformers oils that have been operated 36 years. These transformers were under an annual maintenance and predicated program. Periodical tests have been executed on oil specimens to check properties. Electrical, physical, chemical and thermal properties have been measured according to IEC No. 296 after refining and filtering transformers oils.

The tests results provide that the characteristics of transformers oils after refining process have improved for certain period of time and then the characteristics began to degrade during operating.

Experimental study has been done through this research to evaluate the behavior of transformers oils treated by activated BENTONITE. From the economic aspects, transformers oils are very expensive, so recycling of used transformers oils is very important. Also, recycling used transformers oils give a good solution to avoid environmental pollution.

2. Experimental Techniques

2.1. Transformer Oil Samples

In this research used transformer oil (under service for 36 years) has been tested. In the Experiments the properties of long period used transformers oils have been measured periodically according to IEC specifications.

The transformer has 6.4: 4.6 MVA, 30 kV/(511-702) V, 90/7700 Amp and 9.3 Ton of oil. The purification process was through purification unit (drying and filtering) with a capacity of 2 Ton/hour under vacuum pressure and temperature (80˚C).

In the treatment process, Bentonite material was used with a certain ratio using heating unit and electric equipment for stirring.

2.1.1. Bentonite

The study showed the ability of activated Bentonite material to remove totally all contaminants, ash and carbon contents in treated oil, comparing with untreated oil.

The paper includes actual comparison between normal refining process and activated Bentonite treatment of the same long operating used transformer oil. By operating the oil for the test period of half year and one year, it has been proved that used oil treated with activated Bentonite gives better results.

2.2. Methods of Preparation and Acidic Activation for BENTONITE

1) BENTONITE raw material is grinded softly.

2) Adding concentrated acid to the grinded BENTONITE.

3) Raising the temperature of the mixture up to 70˚C with continuous stirring for about half an hour.

4) The mixture is left till cooling, and washed through filters for several times till neutralization, and then dried.

5) Regrinding the activated Bentonied material to a fine grade of softness.

2.3. Advantages of Activation Process

1) Increasing the surface area of BENTONITE grains to become able of absorption for impurities, suspended matters, and sediment of used transformers oils.

2) Replacing some of cations such as calcium, sodium, and potassium with hydrogen ions in the material lattice structure.

3) Removing the cations of aluminum, iron, and magnesium from lattice structure, which create micro cavities in the material. Thus it increases surface area obviously from the physical aspect and increases the activation from the chemical aspect.

3. Results and Discussions

3.1. Effect of Purification on the Properties of Used Transformer Oil

Different properties such as; electrical, physical, chemical, and thermal are measured to evaluate the purification process for used transformer oil. The used transformer oil tested before and after purification, and then it was tested after two aging times (half year and one year). A comparison for different properties between four oil samples is shown in **Table 1**. The four oil tested samples are: used transformer oil (sample U), sample U after purification (sample P), sample P after aging of half year (sample PI), and after aging of one year (sample PII).

It can be noticed from the results of table 1 that, the breakdown voltage is 22 kV for used transformer oil (sample U) of 36 years service period. While breakdown voltage of sample P reached to 64 kV. For the aging period of half year, the breakdown voltage of sample PI is 57 kV. The reduction of breakdown voltage for sample PI is almost 10.9%. While the breakdown voltage of sample PII (one year aging period) is 42 kV. The reduction of breakdown voltage for sample PII is almost 34.4%.

Table 1. Properties of used transformer oil before and after purification.

Property \ Sample	U	P	PI	PII
Breakdown voltage (kV)	22	64	57	42
Water content (ppm)	65	18	28	34
Total acidity (mg KOH/g of oil)	0.2	0.08	0.09	0.11
Ash content %	0.1	Nil	Nil	Nil
Carbon content %	0.08	Nil	Nil	Nil
Viscosity (Engler)	1.74	1.72	1.72	1.72
Flash point at 15˚C	147	148	148	148
Spec. gravity at 15.5˚C (g/cm^3)	0.877	0.879	0.882	0.878
Colour	Dark	Dark	Dark	Dark

From the results of physical properties, the water content for transformer oil tested samples are 65, 18, 28, and 34 ppm for U, P, PI, PII samples respectively. While the specific gravity values for U, P, PI, PII samples are 0.877, 0.879, 0.882 and 0.878 g/cm^3 respectively. The viscosity is 1.74 Engler for sample U, and it reaches 1.72 Engler for all purified samples. The color of all samples of used transformer oil is dark either before or after purification.

Chemical properties such as total acidity for sample U, P, PI, PII are 0.2, 0.08, 0.09 and 0.11 mg KOH/g of oil respectively. While ash content is 0.1% and carbon content is 0.08% for sample U. But for all purified samples (P, PI, and PII) the ash and carbon content are Nil.

Flash point at 15˚C as a thermal property is 147 for sample U, while flash point at 15˚C is 148 for all purified transformer oil samples (P, PI and PII).

3.2. Treatment with Activated BENTONITE Effect on Different Oil Properties

After adding an activated BENTONITE material to the purified used transformer oil by using a treatment unit, all oil properties have been measured. Transformer oil after treatment with activated BENTONITE was tested. The treated transformer oil properties were evaluated in two periods of aging (half year and one year). A comparison for electrical, physical, chemical, and thermal properties between used transformer oil before and after treatment is shown in **Table 2**. Used transformer oil (sample U), sample U after BENTONITE treatment (sample T), sample T after aging of half year (sample TI), and after aging of one year (sample TII).

The results of **Table 2** shows that, sample U has a 22 kV of breakdown voltage, while the treatment process reaches the value of breakdown voltage up to 68 kV (sample T). The value of breakdown voltage for the sample after aging of half year is 61 kV (sample TI), and is 60 kV for sample TII of one year aging. The reduction of breakdown voltage for samples TI and TII are 10.3% and 11.8% respectively.

Physical properties such as; water content for sample U is 65 ppm, while it reaches 14 ppm for all treated samples (T, TI and TII). Viscosity of used transformer oil sample U is 1.74 Engler, but for all treated samples the value of viscosity is 1.70 Engler. The specific gravity value for all tested samples is 0.877 g/cm^3. The color of sample U is dark, but it's clear in all treated samples even sample TII of one year aging it's clear and free of suspended matter and sediment.

From the result of chemical properties, total acidity for sample U is 0.2 mg KOH/g of oil, and for sample T is 0.016 mg KOH/g of oil. The total acidity for the aged oil sample for half year (TI) is still 0.016 mg KOH/g of oil, but it reaches 0.022 mg KOH/g of oil for the sample of one year aging (TII). The ash content of sample U is 0.1% and carbon content is 0.08%. But for all treated samples (T, TI and TII) the ash and carbon content are Nil.

The flash point at 15˚C is 147 for sample U, while flash point at 15˚C is 148 for all treated transformer oil samples (T, TI and TII).

3.3 Comparison between Purification Process and Treatment process for Recycling Oil

Recycling used transformer oil is a very important process from many aspects. Degradation in all oil properties was found in the used transformer oil of 36 years aging. Also, the properties values were over the limits of IEC no 296. For example; breakdown voltage decreased,

Table 2. Properties of used transformer oil before and after activated Bentonite treatment.

Property \ Sample	U	T	TI	TII
Breakdown voltage (kV)	22	68	61	60
Water content (ppm)	65	14	14	14
Total acidity (mg KOH/g of oil)	0.2	0.016	0.016	0.022
Ash content %	0.1	Nil	Nil	Nil
Carbon content %	0.08	Nil	Nil	Nil
Viscosity (Engler)	1.74	1.70	1.70	1.70
Flash point at 15˚C	147	148	148	148
Spec. gravity at 15.5˚C (g/cm^3)	0.877	0.877	0.877	0.877
Colour	Dark	Clear	Clear	Clear

water content and total acidity, impurities, suspended matter, sediment and carbon content increased, and color changed to dark brown with a smell.

The purification process improved the oil properties for certain values but treatment process with activated BENTONITE highly improved all oil properties values.

3.3.1. Electrical Properties

Figure 1 shows a comparison of breakdown voltages between purified oil and BENTONITE treated oil. According to IEC no. 296, breakdown voltage ranged from 30 to 50 kV, the purification process improved breakdown voltage of used transformer oil from 22 kV to 64 kV, while adding activated BENTONITE in the treatment process improved breakdown voltage from 22 kV to 68 kV. That means that the breakdown voltage has improved in the purification process by almost 190.9%, while it's improved in the Bentioniet treatment process by almost 209.1%.

In **Figure 1**, it's noticed that after half year of operation, recycled transformer oil breakdown voltage reached 57 kV for sample PI, and 61 kV for sample TI. After one year of operation, recycled transformer oil breakdown voltage reached 42 kV for sample PII, and 60 kV for sample TII. It means that activated BENTONITE increased electrical performance of used transformer oil that the breakdown voltage was improved by almost 7% in the half year aging sample comparing with the sample of purified oil without using BENTONITE. As for the samples of one year aging, the BENTONITE treated sample was highly improved by almost 42.9% than the purified sample without using BENTONITE.

Degradation observation of oil properties shows that, after one year of aging the breakdown voltage of transformer oil decreases 15 kV for purified oil, while it decreases only 1 kV for BENTONITE treated oil.

3.3.2. Physical Properties

Physical properties such as; water content (ppm) ranged 13 - 30 ppm according to IEC No. 296 and used transformer oil reached 65 ppm. **Figure 2** shows a comparison of water content improvement between purified aged transformer oil and activated BENTONITE treated aged transformer oil.

From the result of **Figure 2** it can be noticed that, the water content improved after purification of transformer oil, as it reached 18 ppm. While using activated Bentonite as a treatment of aged transformer oil (40 years of aging), the water content reached 14 ppm. After half year transformer oil operating, water content of purified oil was 28 ppm, it reached 34 ppm after one year. But water content of Bentonite treated transformer oil was still 14 ppm even after one year operating. It may be attributed to ability of activated Bentonite material to absorb moisture from transformer oil.

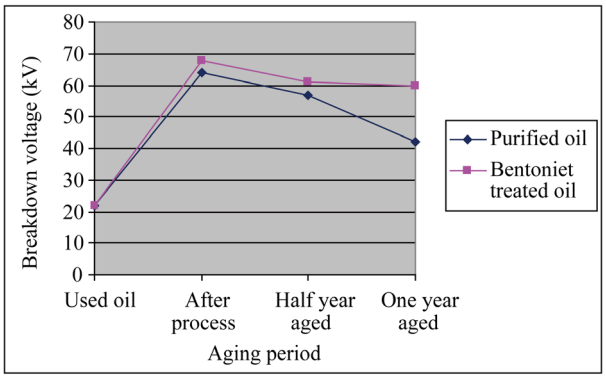

Figure 1. Breakdown voltages of purified oil and BENTONITE treated oil.

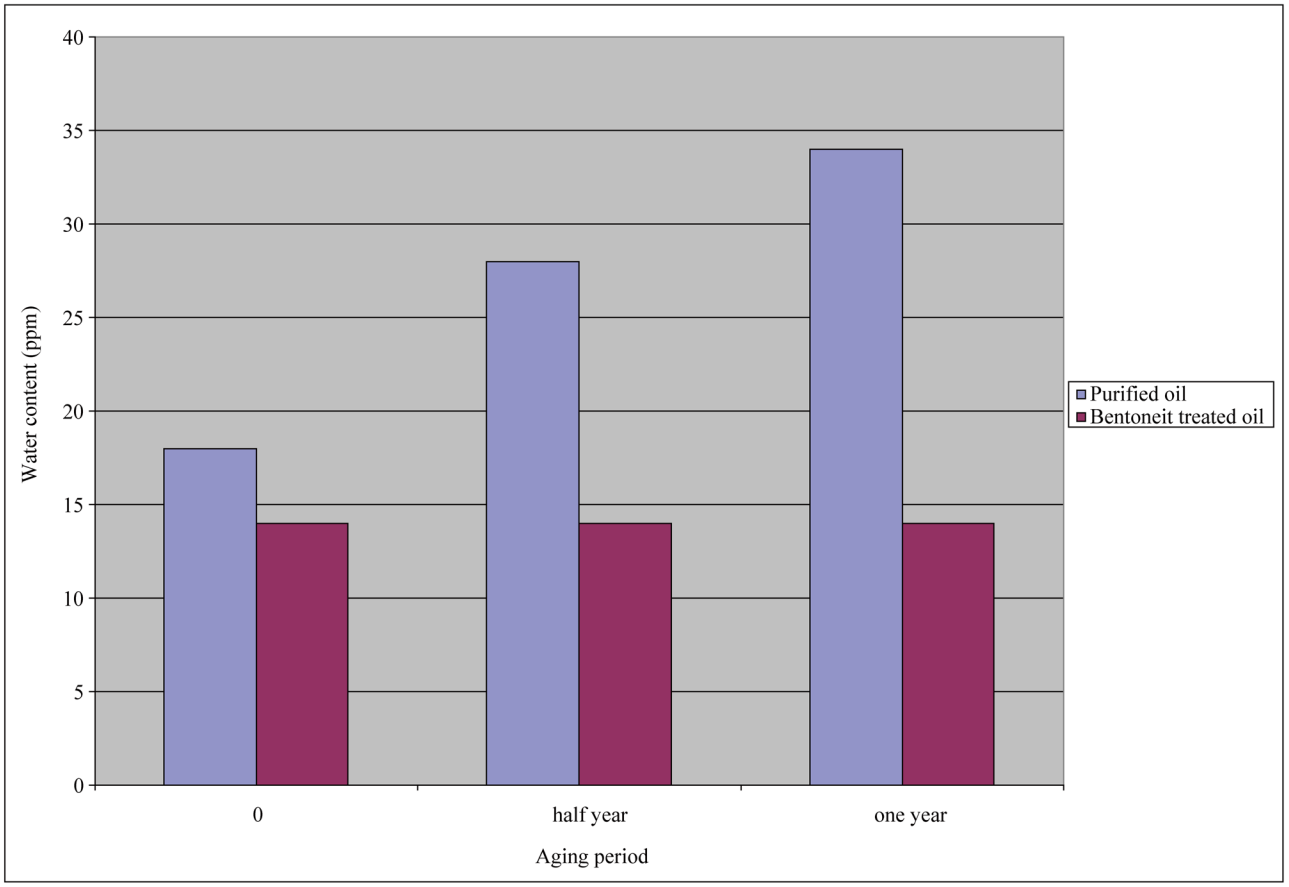

Figure 2. Water content (ppm) for aged transformer oil after purification and activated Bentonite treatment.

Viscosity of used transformer oil was 1.74 Engler. After oil purification, viscosity was 1.72 Engler, and continued to be the same value for even after one year operating. While viscosity value was 1.70 Engler after using Bentonite material and also still reached the same value for even after one year operating.

Specific gravity at 15.5˚C was 0.877 g/cm^3 for aged transformer oil. It increased to 0.879 g/cm^3 for purified oil, but with using activated Bentonite in treatment of transformer oil it was still 0.877 g/cm^3. After half year of transformer oil operation, specific gravity of purified oil was 0.882 g/cm^3 and it was 0.878 g/cm^3 after one year of operation. In the case of activated BENTONITE treatment, specific gravity was still 0.877 g/cm^3 and didn't change for one year of operation.

The color of used transformer oil is dark even after purification and continuous using for one year. But the color is clear in all Bentonite treated samples even after one year operating, and it's free of suspended matter and sediment.

3.3.3. Chemical Properties

According to IEC No. 296, the total acidity is 0.03 mg KOH/g of oil maximum. Aged transformer oil either before purification or before treatment has a total acidity of 0.2 mg KOH/g of oil, which mean that it is over the IEC limits by almost 85%. But total acidity decreased by almost 60% for purified oil (0.08 mg KOH/g of oil) and 92% for BENTONITE treated oil (0.016 mg KOH/g of oil).

After half year of aging, the total acidity of purified transformer oil increased to 0.09 mg KOH/g of oil, but it was still the same value of 0.016 mg KOH/g of oil for the Bentonite treated transformer oil. After one year of aging, the total acidity of purified transformer oil increased to 0.11 mg KOH/g of oil, and 0.022 mg KOH/g of oil for the Bentonite treated transformer oil.

Recycling used transformer oil with either purification or Bentonite treatment shows nil of ash and carbon contents even after one year of operating.

3.3.4. Thermal Property

Flash point at 15˚C for used transformer oil was 147˚C; hence, the value according to IEC no. 296 is 154˚C. The flash point value was 148˚C in either purified or Bentonite treated transformer oil and continued as the same

value for even after one year operating.

4. Harmful Environmental Effects of Used Transformers Oils

1) Used transformers oil is classified as a hazardous waste environmentally, because of its chemical reaction, toxicity, flammability, or ability of explosion.

2) Generally transformers oil is considered heavy metals, non-volatile, and has high molecular weight. When it's spilt in the ground, it spreads easily horizontally and covers a large area separating between the air and the layers of soil.

3) Aged transformers oil contains some toxic chemical resulted of additives to improve oil properties such as heavy metals, organic materials (phenol), and special synthetic transformers oils, which are very toxic, carcinogenic, soluble in water and penetrate in the soil and underground water.

5. Conclusions

Work has been done to understand the different properties such as electrical, physical, chemical and thermal of power transformer oil after 36 years in service and then treated with activated Bentoneit. The following conclusions may be drawn:

1) High improvement of breakdown voltage occurs after using activated Bentonite treated transformer oil and reaches 68 kV.

2) After one year aging for Bentonite treated transformer oil, some improvements have been achieved. Water content improved 78.5%, total acidity 89% and flash point 1˚C.

3) Economically the actual cost for one tone of activated Bentonite treated oil is only 10% of oil price. Ore material of Bentonite is available at many places in Egypt with low costs.

Environmentally, after activated BENTONITE treatment process for the used transformer oil, activated Bentonite is filtered and can be recycled by re-using it in many applications like wells digging and molding.

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