PERFORMANCE OF ACTIVATED BENTONITE AND CARBON IN RECLAIMING THE PROPERTIES OF USED MINERAL OIL

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Abstract*: In transformer, petroleum based mineral oil is used as insulation and coolant over many years. The environmental issue related with the present liquid insulation system is the disposal of used oil samples after prolonged service. The disposal problem arises due to the non biodegradable nature of mineral oil which may harmful and pollute the surrounding places. To avoid the disposal problems, this work focuses on study the influence of activated bentonite and carbon absorbents in reclaiming the properties of used mineral oil to analyze the re-usage characteristics of used mineral oil samples after reclaiming treatment. Reclaiming treatment is conducted with 500ml of used mineral oil and with individual combinations of 1g, 2g, 5g and 10g and blended combinations of two absorbents. The properties of oil samples such as breakdown voltage, flash point, fire point, viscosity, interfacial tension, water content and acidity are measured before and after reclamation treatment based on the international standards. From the investigation, it is understandable that the individual and blended combinations of activated absorbents have improved the properties of used mineral oil after treatment. The reclaimed oil sample has the potential to be reused as liquid insulation.*

Key words: *Dielectric breakdown, oil insulation, transformers, used mineral oil, activated bentonite, activated carbon*

1. INTRODUCTION.

In electric power transmission and distribution networks, power transformers are the most important equipments in delivering consistent and capable electricity supply for consumers [1]. Life of transformers can be determined by conditions of insulation used in it [2]. Solid (paper and pressboard) and liquid (transformer oil – hydrocarbon based mineral oil) insulations are traditionally used as two insulating medium in the transformers. Specifically liquid insulations are playing the leading role due to its diverse functioning as both insulation and coolants [3, 4].

In transformers, mineral oil exerted from crude petroleum oil which contains the combination of hydrocarbons. Several billion liters of mineral oil is used as dielectric medium in transformers worldwide for more than 70 years due to its low cost and better performance [5]. The electrical and physicochemical properties of insulations get depreciated during continuous operating service and also due to stresses such as thermal and electrical stress. After depreciation of oil insulation quality and its continuous use in transformer may lead to unpredicted damage to transformers [6].

Nowadays the abundant usages of mineral oil and present scenario of availability of petroleum products focuses towards conserving and reducing its usage. Also concerns over environmental aspects on traditional mineral oil disposals are key limitation which affects human life and ecosystems [7-10]. The above aspects are heading towards a new research focus in liquid insulations for maintaining equilibrium between forecast of present and future requirements. Please stick the figures in the text, as the paper shall look in the final form.

Synthetic liquids like silicone oil and perchloroethyleneare have been used in transformers. Their usage is restricted to only for special applications due to its high cost [11]. Presently more research works are going on related with natural liquids which have high grade dielectric nature [12-17]. Both synthetic and natural liquids have different characteristics, hence direct substitutions on in-service transformer units are not possible [17].

The degradation of insulation in power transformer is majorly influenced by operating condition and temperature. Under thermal stress, the liquid insulation inside the transformer had undergone many changes in their structure and performance. This will affect the life of transformer if the thermal stress continued for many years [18]. The disposal of degraded or used mineral oil is a serious problem to human and environment. So the refining/reclaiming is the one of simple and easiest way to avoid those problems. In the refining process of commercial oil insulation, natural oil inhibitor (2, 6 – di tertiary butylphenol and 2, 6 – di tertiary butyl para cresol) are used in smaller quantity depended on the inhabitant of oxidation product, catalytic intermediaries and impurities in the oil. In modern system, the contact with atmospheric oxygen is minimized by sealing the interior of transformer. The oxidation process results in generation of byproduct such as acid and sludge which are the influential elements towards menace to the reduction of properties of liquid mineral oil [18].

The effective way of utilizing the available resources is reclaiming of used mineral oil with activated absorbents to guard the environment and maintain equilibrium between present and future demand forecasts [18]. Absorbance process is concerned as economical way for reclaiming oil properties. Activated bentonite treated used mineral oil has less content of unnecessary chemical elements [19]. Activated carbon is used to remove the sludge contaminations, acids and etc. during regeneration process [20]. Both activated bentonite and carbon are having high absorption capacity during oil reclaiming process.

In this study, an effort is made to investigate the influence of combined effect of activated bentonite and carbon on the properties of used mineral oil. Before and after the reclaiming processes, used mineral oil samples are tested for breakdown voltage, flash point, fire point, viscosity, interfacial tension, water content and acidity as per specified standards.

2 SAMPLE DESCRIPTIONS

Based on the literature in activated absorbent, the bentonite clay and carbon are selected for this investigation to reclaim the properties of used mineral oil. This method of reclaiming is the economic way of reusing the used mineral oil with better performance characteristics.

2.1 Activated Absorbent

Bentonite clay (also termed as "green healing clay") is formed in naturally by the combinations montmorillonite (volcanic ash) and water. The natural form of bentonite clay is hydrated aluminum silicate which may contain potassium, calcium and sodium based on the source of occurrence.

Under wet condition, the sponge like expansion o bentonite absorbs the polar contaminants and toxin like magnet and positioned in the pores where the toxins are reacted with chemical of clay [18]. Th monotmorillonite content in bentonite is directly influenced in their absorption properties. Bentonite clay is majorly used in removal of contaminant meta ions from liquid medium [19, 21].

Carbon products (Charcoal) are formed for agricultural products. These products are used in various industrial applications such as treatment of waste water, purification of gas (air) and clean up of spill. The micro porous nature and larger surface are available in carbon products improve the absorption capacity [20].

The acid activation process yields the more efficient absorbents with better absorption characteristics. For removing impure materials and replaceable ions in absorbent materials, materials are modified with an acid to produce activated absorbents. Activation process is carried by inclusion of either sulphuric or hydrochloric acid to remove exchangeable ions from absorbent. The activation process has improved the bleaching capacity and adsorptive properties of absorbent materials [22]. Both the activated bentonite and carbon materials are purchased from the local chemical suppliers.

2.2 Oil Sample Details

In this work, used mineral oil (UMO) samples are considered for investigations to analyze validity of reclaimed properties of used mineral oil after processing of activated bentonite and carbon.

Unused mineral oil sample is bought from transformer servicing company in local region. Used mineral oil sample has been collected from 150kVA, 11kV/430V, step-down transformer which under service for more than 8 years.

The service period of transformer indicates sure decreasing in properties of used oil samples due to presence of contaminants, sledges and oil degradation byproducts.

Oil samples are prepared by processing used mineral oil samples with activated bentonite and carbon as individually and blended combinations.

Various samples prepared with used mineral oil, activated bentonite (AB) and activated carbon (AC) are tabulated in Table 1 and 2 respectively for individual and blended combinations of absorbents respectively.

A 500 ml of used mineral oil is taken for each sample and is mixed with a specified quantity of various combinations of reclaiming agents. Before adding reclaiming agents, the each oil sample is treated thermally to the temperature of 80°C.

Mixing process is carried out in a magnetic stirrer with strong mixing speed upto 1000 rotations per minute. Process of mixing continued until complete dispersion of reclaiming agents in the used oil samples. Prepared oil samples are then filtered to remove the dispersed agents from oil using Whatman filter paper No. 42. The experimental procedure was pictorially illustrated in Fig. 1.

Table 1. Samples Prepared With AB and AC

Samples	Combinations	Samples	Combinations
A1	UMO + 1 g of AB	B1	UMO + 1 g of AC
A2	UMO + 2 g of AB	B2	UMO + 2 g of AC
A3	UMO + 5 g of AB	B3	UMO + 5 g of AC
A4	UMO + 10 g of AB	B4	UMO + 10 g of AC

Table 2. Samples Prepared With Blended AB and AC

Samples	Combinations	Samples	Combinations
C1	UMO + 1 g of AB+ 1 g of AC	D1	UMO + 2 g of AB+ 1 g of AC
C2	UMO + 1 g of AB+ 2 g of AC	D2	UMO + 2 g of AB+ 2 g of AC
C3	UMO + 1 g of AB+ 5 g of AC	D3	UMO + 2 g of AB+ 5 g of AC
C4	UMO + 1 g of AB+ 10 g of AC	D4	UMO + 2 g of AB+ 10 g of AC
E1	UMO + 5 g of AB+ 1 g of AC	F1	UMO + 10 g of AB+ 1 g of AC
E2	UMO + 5 g of AB+ 2 g of AC	F2	UMO + 10 g of AB+ 2 g of AC
E3	UMO + 5 g of AB+ 5 g of AC	F3	UMO + 10 g of AB+ 5 g of AC
E4	UMO + 5 g of AB+ 10 g of AC	F4	UMO + 10 g of AB+ 10g of AC

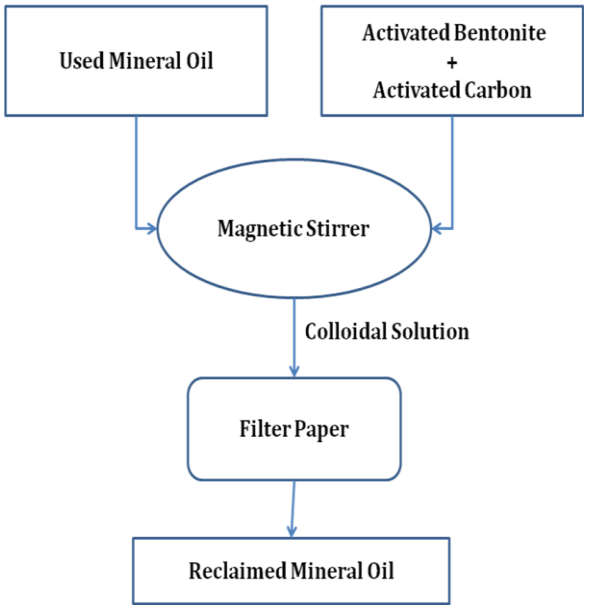

Fig. 1. Experimental Procedure – Flowchart

3 EXPERIMENTAL PROCEDURES

For analyzing the influence of activated bentonite and carbon in reclaiming the properties of used mineral oil, the critical properties such as breakdown voltage, flash point, fire point, viscosity, interfacial tension, water content and acidity of used mineral oil are measured before and after the additions of activated absorbents. All the measurements are carried out at room temperature.

Breakdown voltage plays a very important part in evaluating the quality of insulating oil. Breakdown voltage of insulating oil should be high enough to withstand high electrical stress has been developed inside transformers.

Breakdown voltage depends on various other factors such as moisture, suspended solid contaminants, air pockets, etc. [6, 12-20, 23-25]. Breakdown voltages of investigating samples are measured in breakdown voltage test cell with 2.5mm spaced special electrodes as per IEC60156 [26]. Breakdown voltages of samples are measured by varying input voltage at the rate of 2kV/s.

The five values breakdown voltages are measured for each sample by providing few minutes between each measurement. The mean of five breakdown voltages is considered as breakdown voltage of that sample.

Flash point and fire point are indication of temperatures which are safest temperature limit inside the temperature [6, 12-20, 23-25]. Based on the standard ASTM D93, flash point and fire point are measured in the Pensky Martin flash point apparatus [27]. A 60 ml of oil sample is taken on test cell and the temperature of that sample is increased by using electric heater.

Flash point and fire point are identified by introducing a test flame in the test orifice in apparatus. Indication for the flash point is temporary flame on the surface of oil sample in the test cell. Fire point is detected by the contentious flame on the surface. Fire point is always greater than flash point.

Viscosity of liquid medium is a measure of oil flow nature on the surface. The property of oil insulation as coolant is indirectly depending on the viscous nature of oil [6, 12-20, 23-25]. The standard ASTM D445 is used in the measurement of time taken for 50ml oil flow in Redwood Viscometer to calculate the viscosity [28].

Interfacial tension is the measure of attractive force in the oil and water interface which indicates the resistance offered to external contaminants inside oil [24]. Interfacial tensiometer is used to measure the interfacial tension by Ring method as per standard ASTM D971 [29]. The force measured in the process is used to calculate the interfacial tension between oil and water interface.

Water content in the oil is the indication of poor dielectric medium. Water content in the oil will cause the acid contaminants and life of oil [23-25]. Water content is measured by Karl Fischer Coulometer with moisture sensor based on the standards ASTM D1533 [30]. The moisture sensor sense and display the amount of water content.

Acidity of oil samples is the indication of presence of free organic and inorganic acids. The higher for acidity in oil sample increases the corrosion and deformation process inside the

equipment which will further increase the acidity [23 - 25]. Karl Fischer titration method is used to measure the acidity according to the standard ASTM D974 [31]. The acidity is the amount of potassium hydroide added to one gram of oil to neutralize the hydrogen ions. The phenolthelene indicator is used for indicate neutralize point.

4 RESULTS AND DISCUSSIONS

In this section, properties of used mineral oil and reclaimed oil are presented and discussed. The properties of used mineral oil sample are tabulated in Table 3.

Table 3. Properties of Used Mineral Oil

Properties	Used Mineral Oil
Breakdown Voltage (kV)	21.2
Flash point (°C)	130
Fire Point (°C)	140
Viscosity (cSt)	43.19
Interfacial Tension (mN/m)	28
Water Content (ppm)	22
Acidity (mg KOH/g)	0.23

By seeing the values of properties of used mineral oil, it is evident that the properties are degraded and its values are varied after its usage in transformer. Only water content lies in the acceptable range. All other properties have much lower values than that of specified in standards. The change in properties is due to continuous electrical and thermal stress encountered by mineral oil inside the transformer for 5 years.

4.1 Properties of Reclaimed mineral oil

Used mineral oil samples are treated with individual and mixed (blended) combinations of activated bentonite and carbon for reclaiming its insulating properties.

The properties of oil samples which are individually treated with activated bentonite and carbon are provided in the Table 4. The blended combination of activated bentonite and carbon are used to reclaim the used mineral oil whose properties are listed in Table 5. The variations in properties are pictorially shown in Fig2.

From the measurement values of properties of used mineral oil after treatment with activated bentonite and carbon, the following inferences are made.

- The properties of used mineral oil are varied after treating with activated absorbents. The variations mainly depend on the type and quantities of activated absorbent used for treatment.
- The properties of reclaimed mineral oil such as breakdown voltage, flash point, fire point, interfacial tension have shown improved values than that of used mineral oil. The properties such as viscosity, water content and acidity have shown decrement pattern for reclaimed mineral oil.
- The influence absorption characteristics of activated absorbents in the used mineral oil are the reason for changes in its properties after treatment process.
- By comparing all oil samples prepared in this investigation, enhanced properties of oil samples are obtained with blended combination of activated absorbents than the individual combination of activated absorbents. Among the blended combination, the sample treated with higher concentration of activated carbon has shown better performance in reclaiming process.

Table 4. Properties of Reclaimed Mineral Oil with Activated Bentonite and Carbon (Individual Combination)

Samples	Breakdown Voltage (kV)	Flash point (°C)	Fire Point (°C)	Viscosity (cSt)	Interfacial Tension (mN/m)	Water Content (ppm)	Acidity (mg KOH/g)
A1	22.8	134	145	41.59	28	21	0.19
A2	23.17	137	151	40.79	28	21	0.18
A3	23.6	145	159	39.46	29	21	0.18
A4	24	152	166	37.59	29	21	0.17
B1	28.4	141	159	42.39	29	21	0.17
B2	29.4	149	163	41.06	29	21	0.16
B3	29.8	152	165	38.92	30	20	0.16
B4	29.8	157	170	37.32	30	19	0.13

Table 5. Properties of Reclaimed Mineral Oil with Blended Activated Bentonite and Carbon

Samples	Breakdown Voltage (kV)	Flash point (°C)	Fire Point (°C)	Viscosity (cSt)	Interfacial Tension (mN/m)	Water Content (ppm)	Acidity (mg KOH/g)
C1	30	141	163	41.86	29	21	0.17
C2	30.4	149	166	40.26	30	20	0.16
C3	31	156	174	38.66	32	20	0.16
C4	31.2	160	178	37.05	36	18	0.14
D1	28.4	149	157	41.06	29	21	0.17
D2	29.0	152	163	38.92	29	20	0.16
D3	29.8	156	166	37.85	32	19	0.14
D4	30.6	158	170	36.78	37	18	0.14
E1	28.2	156	166	41.32	29	21	0.17
E2	28.8	163	171	39.72	30	20	0.16
E3	29.4	166	177	38.12	34	19	0.14
E4	31	171	182	36.51	36	18	0.13
F1	28.4	156	167	41.06	30	21	0.17
F2	29.6	159	173	39.46	31	20	0.16
F3	29.6	161	178	37.59	34	19	0.14
F4	30.2	163	182	35.98	36	19	0.14

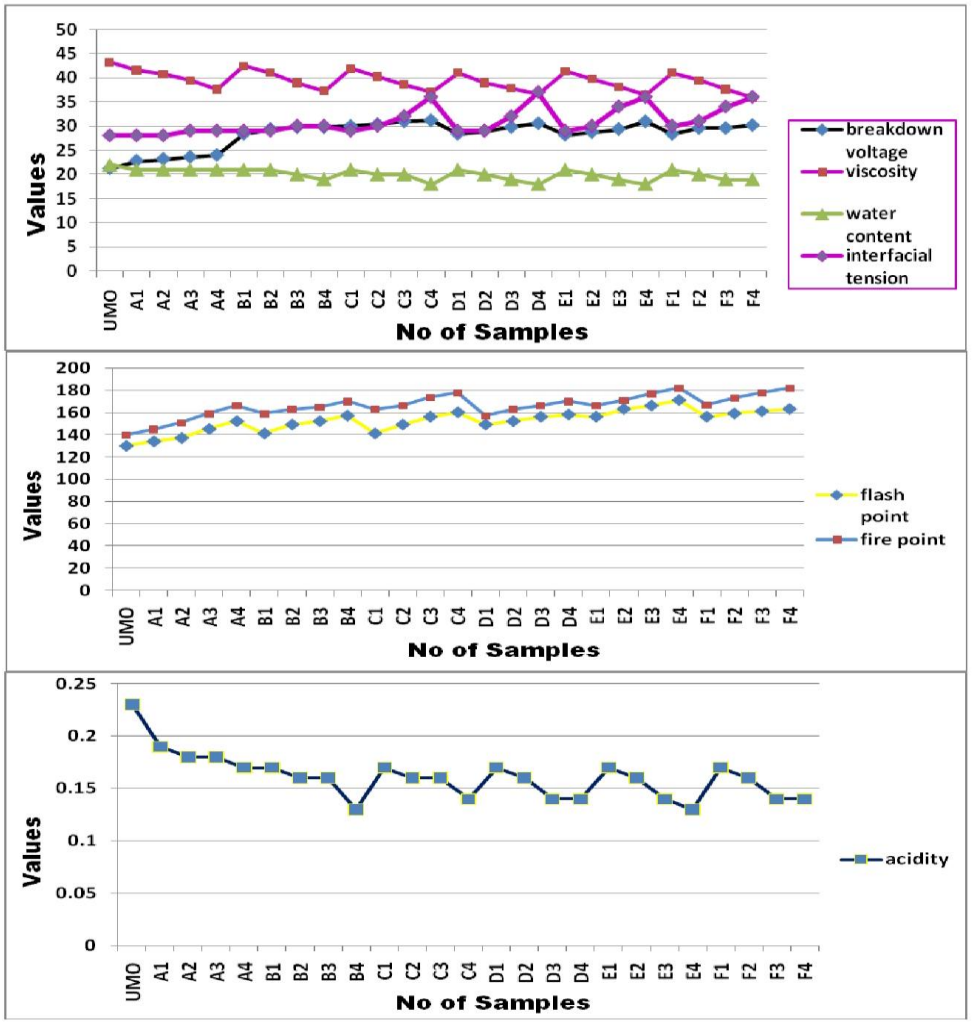

Figure 2. Comparison of Properties of All Samples Prepared with Used MineralOil
(a). Breakdown Voltage, Visocity, Water Content, Interfacial Tension (b). Flash point, Fire point and (c).Acidity

4.2 Effects of AB and Carbon on Properties of UMO

The percentage of enhancement/decrement in properties of used mineral oil after treated with activated absorbents are tabulated in Table 6 and Table 7 respectively for activated bentonite and carbon.

By the obtained results for the treated used mineral oil with activated bentonite and carbon individually, the following conjectures are made.

- All the properties of reclaimed mineral oil have shown better values than that of used mineral oil.
- Breakdown voltage has improved as increasing the quantity of activated absorbents. Similar trend has shown for the flash point and fire point temperature.
- Viscosity and acidity have shown decrement nature as increasing the quantity of activated absorbents.
- In A1 and A2 samples, there are no variations in interfacial tension. The samples A3, A4, B1 and B2 have same increment percentage after treatment process. Same percentage of increment in interfacial tension has obtained for the samples B3 and B4.
- Except the samples B3 and B4, all other samples have the decrement percentage on water content after the reclaiming treatment. Higher percentage of reduction on moisture content has obtained for sample B4.
- The enhancement/decrement percentage for reclaimed oil properties is higher for activated carbon than activated bentonite at the same quantities.
- The changes in properties after reclaiming process is due to the absorption of contaminants present in the used mineral oil by activated bentonite and carbon.
- The activated bentonite treated oil samples have increased due to the absorption contaminants, metal ions and sludge present in the used mineral oil.
- Enhancement in the properties for activated carbon treated oil sample is due to the micro porous nature and larger surface area available in carbon product improves the absorption capacity.

4.3 Effects of Blended AB and Carbon on Properties of UMO

The percentages of enhancement/decrement in properties of used mineral oil after treated with blended activated absorbents are tabulated in Table 8.

By the obtained results for the treated used mineral oil with blended combinations of activated bentonite and carbon, the following implications are made.

- In all the samples prepared with blended absorbents, the properties such as breakdown voltage, flash point, fire point and viscosity have shown incremental nature after treatment. At the same time, viscosity, water content and acidity are reduced from its value under untreated condition.
- In all the combinations of activated absorbents, as the quantity of activated carbon increase, the properties have shown better values. Because of higher absorption capacity of carbon.
- In blended combinations of activated absorbents, the treatment has shown mixed results of enhancement/decrement on properties after treatment.
- From overall investigations, it is evident that the activated absorbents have improved the properties of used mineral oil in individually and blended combinations after treatment.

Table 6. Enhancement in Properties of Used Mineral Oil with AB

Samples	Enhancement Percentage (%)						
	In Breakdown Voltage	In Flash point	In Fire Point	In Viscosity	In Interfacial Tension	In Water Content	In Acidity
A1	7.56	2.86	3.78	-3.7	0	-4.55	-17.39
A2	9.27	5.71	8.11	-5.56	0	-4.55	-21.74
A3	11.32	11.43	13.51	-8.64	3.57	-4.55	-21.74
A4	13.21	17.14	18.92	-12.97	3.57	-4.55	-26.09

Table 7. Enhancement in Properties of Used Mineral Oil with AC

Samples	Enhancement Percentage (%)						
	In Breakdown Voltage	In Flash point	In Fire Point	In Viscosity	In Interfacial Tension	In Water Content	In Acidity
B1	33.96	8.57	13.51	-1.85	3.57	-4.55	-26.09
B2	38.68	14.29	16.76	-4.93	3.57	-4.55	-30.43
B3	40.57	17.14	17.84	-9.89	7.14	-9.09	-30.43
B4	40.57	21.14	21.08	-13.59	7.14	-13.64	-43.48

Table 8. Enhancement in Properties of Used Mineral Oil with Blended AB and AC

Samples	Enhancement Percentage (%)						
	In Breakdown Voltage	In Flash point	In Fire Point	In Viscosity	In Interfacial Tension	In Water Content	In Acidity
C1	41.51	8.57	16.76	-3.08	3.57	-4.55	-26.09
C2	43.4	14.29	18.92	-6.78	7.14	-9.09	-30.43
C3	46.23	20	24.32	-10.49	14.29	-9.09	-30.43
C4	47.17	22.86	27.03	-14.22	28.57	-18.18	-39.13
D1	33.96	14.29	12.43	-4.93	3.57	-4.55	-26.09
D2	36.79	17.14	16.22	-9.89	3.57	-9.09	-30.43
D3	40.57	20	18.92	-12.36	14.29	-13.64	-39.13
D4	44.34	21.71	21.08	-14.84	32.14	-18.18	-39.13
E1	33.02	20	18.92	-4.33	3.57	-4.55	-26.09
E2	35.85	25.71	22.16	-8.03	7.14	-9.09	-30.43
E3	38.68	28	26.49	-11.74	21.43	-13.64	-39.13
E4	46.23	31.43	29.73	-15.47	28.57	-18.18	-43.48
F1	33.96	20	19.46	-4.93	7.14	-4.55	-26.09
F2	39.62	22.29	23.24	-8.64	10.71	-9.09	-30.43
F3	39.62	24	27.03	-12.97	21.43	-13.64	-39.13
F4	42.45	25.71	30.27	-16.69	28.57	-13.64	-39.13

5 CONCLUSION

To eliminate the disposal problem related with used mineral oil and utilize the same for re-usage as liquid insulation, the used mineral oil is treated with activated bentonite and carbon in the reclaiming treatment process. The performance of activated bentonite and carbon in reclaiming the used mineral oil is studied in this work by measuring the oil properties after treatment with activated absorbents in individual and blended combinations. From the investigation, it is evident that the both individual and blended combinations of activated absorbents have improved the used mineral oil properties after reclaiming treatment process. Among the two activated absorbents, activated carbon has shown superior performance in reclaiming than the activated bentonite. Based on the optimized selection of suitable combinations of activated absorbents, performance and properties of reclaimed mineral oil will be improved for the applications in high voltage transformer. This work may be extended to improve the properties of reclaimed oil with other physical and/or chemical process for the usage in transformer with the considerations of environmental and economic perspectives.

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