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Improving the Thermal and Electrical Properties of Transformer Oil Using Hybrid Nanofluid

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Abstract-*Improving the insulating and thermal properties of transformer oil is one of the factors in the use of nanoparticles (NPs) in oil. However, the use of NPs may only have a positive effect on some properties of the oil or even have a negative effect on the other properties of the oil. For this reason, hybrids nanofluid (HNF) were used to improve the properties of the transformer oil. By performing the Breakdown Voltage (BDV) test on different weight percentages (wt%) of TiO_2 and CNT, it was proved that the best wt% for TiO_2 is 0.0075 and for CNT is 0.001 to maximize the BDV. In this case, the HNF was able to improve the BDV and heat transfer by 9% and 8%, respectively. Another surprise that the HNF has been able to reduce the amount of C_2H_4 and C_2H_6 dissolved in oil by more than 70%. This reduction in the number of gases has another very desirable result and has reduced the PD by 63%. HNF proved that by using the right combination of different nanomaterials in transformer oil, more properties of the transformer oil can be improved.*

Keyword: Transformer oil, Hybrids Nanofluid, Breakdown voltage, Partial Discharge, Dissolved Gas Analysis, Nanoparticle.

1. INTRODUCTION

Power transformers play a vital role in the power system as the reliability of the entire network depends on this equipment [1-3]. Thermal and electrical faults in oil-filed transformers cause the production of various gases such as hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4), and ethane (C_2H_6) in the oil [4, 5]. The amount and type of fault gases are very much dependent on the type of faults such as partial discharge (PD), arching, and thermal faults [4, 6]. Among the fault gases mentioned, even though some minor faults in the transformers may lead to the spark discharge in the transformer oil, then cause the oil to decompose and produces C_2H_6, C_2H_4 gases, less research has been done on these two gases. In addition, it has been shown that C_2H_4 may be produced abnormally at low temperatures [7]. These faulty gases, if produced rapidly, either accumulate as a gas above the oil or, in most cases, dissolved in transformer oil. Therefore, detection and analysis of the varieties, quantities, and production rates of these fault gases presented in the transformer oil allow for identification of power transformer fault types such as sparking, overheating, corona, and arcing [1].

In recent years, several methods have been proposed for the analysis of fault gases dissolved in transformer oil. One of the proposed methods is dissolved gas analysis (DGA) [8, 9]. one of the major detection methods is gas chromatography (GC). GC using a sample of oil extracted from the transformer and for this reason it is highly reliable. However, it does not allow to detection of fault gases in real-time because of a minimum analysis period ranging between two hours to more than a full day is required [10]. Lately, a range of spectroscopic methods has been applied to detect dissolved gases such as photoacoustic [11], laser calorimetry [12], tunable diode laser absorption spectroscopy [13], and optical fiber [14]. Nevertheless, these methods show a lower sensation and higher detection border for dissolved gases owing to mechanical vibrations and a notable background signal [13]. One of the best ways to reduce the effect of dissolved gases in transformer oil is to use nanoparticles (NPs) as adsorbents in transformer oil. Nanofluid (NF)

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consists of two parts; A base fluid and NPs. Most nanofluids in transformers are used for various purposes such as improving the thermal coefficient [15], reducing the PD [16], and improving the breakdown voltage(BDV) [17]. Rafiq et al. shown that the addition of Aluminum Nitride NPs in transformer oil not only increased PD inception voltage (PDIV) by up to 20% but also increase the thermal conductivity of the transformer oil by 3-7% compared to pure transformer oil [18]. Akbari et al. showed based on experimental results that adding diamond NPs could lead to an increase in the transformer oil BDV. Results revealed that the AC breakdown strength of NF was almost 1.26 times the base oil breakdown strength, while lightning breakdown voltage (LBDV) increased by almost 24% to that of base oil [19]. Rajkonwar et al. revealed that maximum AC breakdown strength occurs at the optimum concentration of NPs in the transformer oil, after that, a notable decrease was observed mainly due to the agglomeration of NPs inside the fluid [20]. Qing et al. stated that the hydrophilic surface of SiO_2 NPs chains water on the surface, which leads to a decrease in the amount of water, hence increasing the BDV value [21]. Sulemani et al. investigated the effect of NPs on aging and breakdown of vegetable oil and explained how that is considered an alternative insulation medium to transformer oil [22]. As you can see, little research has been done on hybrid nanofluids (HNF).

Herein, to use all the capacities of NPs, a combination of NPs has been used to prepare nanofluids. In the previous work [16], the best weight percentage (wt%) for titanium dioxide (TiO_2), zinc oxide (ZnO), and carbon nanotube (CNT) NPs was presented to maximize the BDV. On the one hand, titanium improves the breakdown voltage and partial discharge, and on the other hand, carbon greatly improves the thermal transfer coefficient. It is a way to take advantage of the positive properties of both nanoparticles and to improve both the temperature transfer coefficient and the breakdown voltage. To achieve this, we must look for hybrid nanoparticles. Continuing the same previous research, this time the combination of TiO_2 and CNT is used to simultaneously use the best properties of both NPs and achieve an ideal HNF. Also, after obtaining the best combination, heat transfer (HT), DGA, and PD tests will be performed. To easily access the abbreviations, the table of abbreviations is given in Table 1.

2. PREPARATION AND EXPERIMENTAL TEST

Specifications of all nanoparticles, optimal wt% of nanoparticles for maximum BDV, PD test and HT results are given in the previous work[16]. Table 2 summarizes the previous work. As can be seen, TiO_2 has the best effect on the BDV but has not significant consequence on HT. On the other hand, CNT have been able to greatly improve HT due to their very high heat transfer coefficient, but due to their high electrical conductivity, unfortunately, they have greatly reduced the BDV. In this research, we try to achieve a hybrid mixture by combining TiO_2 and CNT in order to improve both BDV and HT.

A two-step method has been used to prepare HNF[23]. According to this method, to prepare NFs, the NPs are first exposed to 1600 ° C for 10 hours and then slowly cooled. After cooling, it is poured into the transformer oil and stirred with a magnetic stirrer for 30 minutes to create a homogeneous composition. In the second stage, the samples are sonicated for 2 hours and subjected to a pressure of less than 1 kPa for 48 hours. It should also be noted that all samples are sonicated at room temperature and pressure before performing practical adjustments. To increase the accuracy as well as the correctness of the obtained results, three different wt% of 0.065, 0.075, and 0.085 have been selected for TiO_2 as the base nanoparticle. As seen in the previous work, CNT greatly reduces the BDV even at a very low weight percentage of 0.01; therefore, much lower weight percentages have been used to combine CNT with TiO_2. Selected WT% for CNT 0.001, 0.002, and 0.003 are selected. The BDV test was done on the BAUR PGO S-3 device, according to the IEC 60156 standard. The test device consisted of two spherical electrodes with a distance of 2.5 mm and a voltage increase step of 2 kV/s. The time interval with mixing action after each breakdown was set to 1 min.

Table 1. Abbreviations

Symbol	Description
PD	partial discharge
DGA	Dissolved gas analysis
GC	Gas chromatography
NPs	Nanoparticles
NF	Nanofluid
HNF	Hybrid nanofluids
BDV	Breakdown voltage
HT	Heat transfer
PDIV	Partial discharge inception voltage
LBDV	Lightning breakdown voltage
wt%	Weight percentage
TiO_2	Titanium dioxide
ZnO	Zinc oxide
CNT	Carbon nanotube

Table 2. optimal wt%, BDV,PD test and HT results [16]

	Optimal wt%	BDV (KV)	PD (number)	HT (second)
Pure Oil	-	59	1157	578
TiO_2NF	0.075	68	432	543
ZnONF	0.01	44	621	500
CNTNF	0.01	18	1142	410

Table 3. BDV for all 9 samples

		CNT wt%		
		0.001	0.002	0.003
TiO_2 wt%	0.065	57.2	53.8	51
	0.075	64.3	63.2	62.5
	0.085	60.2	59.6	58.7

Table 4. HT (Second) for all 9 samples

		CNT wt%		
		0.001	0.002	0.003
TiO_2 wt%	0.065	540	523	515
	0.075	530	515	508
	0.085	521	511	501

Table 5. Results of the DGA and PD tests

DGA (ppm)		
	C_2H_4	C_2H_6
Pure Oil	760	63
TiO_2NF	213	18
HNF	208	18
PD		
Pure Oil	1157	
TiO_2NF	432	
HNF	420	

Fig. 1. BAUR PGO S-3 device

3. EXPERIMENTAL RESULTS

The value of the BDV for all 9 samples is given in Table 3. As can be seen, for a given wt% of TiO2, as the wt% of CNT increases, the amount of BDV decreases. This is perfectly in line with the high carbon conductivity. On the other hand, as expected, for a given amount of carbon, the maximum BDV occurred at a wt% of 0.075. The best (maximum) BDV occurs at 0.001 and 0.075 wt% for CNT and TiO_2, respectively, and is equal to 64.3Kv. In this case, the BDV decreased by 5% compared to when TiO_2NF was used, but increased by 9% compared to pure oil. To maximize the BDV, which is the most important insulating property of transformer oil, 0.001 and 0.075 wt% for CNT and TiO_2 (HNF), respectively are used for the rest of our tests.

Table 4 shows the amount of time required (in seconds) to reach a temperature of 25 to 80 degrees Celsius. The shorter the measured time, the easier it is for the sample to transfer heat. The immerse heating method was used to perform this experiment[24]. As can be seen, for a given wt% of TiO_2, as the wt% of CNT increases, the amount of HT decreases. This is completely matched with the high CNT thermal conductivity. As expected, for a given amount of TiO_2, the minimum HT occurred at a wt% of 0.003. HT for an HNF is 530 seconds; This means that the HNF has been able to improve the HT by 8% compared to pure oil.

Table 5 shows the results of the DGA test as well as the PD. As you can see, the HNF has been able to reduce the amount of C_2H_4 and C_2H_6 by just over 71%. The amount of reduction of C_2H_6 gas by HNF was equal to the reduction of this gas by TiO_2. However, the reduction of C_2H_4 by HNF was slightly more than the reduction of this gas by TiO_2. In addition, the HNF has been able to reduce the PD rate by 63%, which is very desirable. Because the main cause of the PD is oil-dissolve gases; It can be concluded that the results obtained from these two experiments are completely consistent and in the same direction. This shows that the HNF could have a more favorable effect than TiO_2 in eliminating the effect of dissolved gases in the transformer oil and consequently reduce the PD.

4. CONCLUSION AND DISCUSSION

The combination of TiO_2 and CNT was considered for use in transformer oil. The choice of these two NPs was due to two reasons: the ability to improve the insulating properties of oil by TiO_2 and the high heat transfer properties of CNT can be used. But the point to pay special attention to was that in previous experiments it was proved that a small amount of CNT also has a very negative effect on the most important property of the oil, namely the BDV. Because TiO_2 was able to trap electrons in the stimulation space, it could improve the breakdown voltage unlike the other nanoparticle.

The results obtained in this work can be summarized as follows:

- In order to improve the insulating properties of oil, special attention was paid to dissolve gases in oil followed by PD. The results obtained from the HNF showed that this combination was able to improve the BDV by 9%.
- the HNF has been shown to have a good ability to increase heat transfer properties and can increase this property by up to 8%.
- But the HNF showed another surprise, and that was the ability of this compound to improve the PD and absorption of oil-dissolve gases. The HNF has been able to reduce the amount of C_2H_4 and C_2H_6 gases dissolved in transformer oil by up to 71%.

- The HNF will also reduce PD by 63% (All comparisons were made to pure oil).

All the results show that the HNF actually has the properties of both TiO_2 and CNT and has been able to improve the insulating and thermal properties of the oil at the same time. The following can be considered for future work:

- Use of other nanoparticles
- A variety of combinations of nanoparticles in order to achieve a specific goal
- Investigate the causes of improvement or degradation of one or more properties of oil when using hybrid nanofluid
- Combining more than two nanoparticles
- Investigation of hybrid nanofluid during normal operation of transformer oil

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