Investigation Of The Effect Of Zinc Nanoparticles (Zno) On The Ac Breakdown Voltage And Acidity Index Of Based Nanofluid On Methyl Ester Of Palm Kernel Oil

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ABSTRACT : In this paper, we address the influence of zinc (ZnO) nanoparticles (NPs) on the AC breakdown voltage (BDV) and acid number (AI) of palm kernel oil methyl esters (MEPKO). To determine this impact, several samples with different concentrations of NPs are prepared by homogenizing the mixtures with an ultrasonic homogenizer. The measurements of breakdown voltage and acidity index are made respectively from the ASTM D1816 and IEC 296 standards. These measurements are made both before and after the addition of zinc nanoparticles. The results obtained allow us to conclude that the acidity index of the MEPKO increases by 320% for a concentration of 0.10% ZnO. For concentrations of 0.15% and 0.20% ZnO, there is an increase of 183% and 116% with respect to the AI of the MEPKO For BDV, there is a recovery of 8% and 3% for 0, 10% and 0.15% ZnO concentrations respectively. For a concentration of 0.20% ZnO, there is a 9% increase in the BDV of MEPKO. This analysis shows that the addition of ZnO to MEPKO has a negative impact on their AI. This is not the case for their BDV which are at two concentrations (0.10% and 0.15%) decreases before increasing for the concentration of 0.20% ZnO.

Index Terms: Breakdown voltage in AC, Acidity Index, Methyl esters of Palm Kernel Oil, ZnO.

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1. INTRODUCTION

Inlong-distance transmission and distribution of electrical energy, transformers are essential components that play a crucial role(A. Beroual, U. Khaled, and A. M. Alghamdi, 2020, pp. 125797-125805)[1]. During operation, transformers generate a significant amount of heat(C. Olmo, I. Fernandez, A. Santisteban, C. Mendez, F. Ortiz, and A. Ortiz, 2019, pp. 1-4), (S. Oparanti, A. Khaleed, and A. Abdelmalik, 2021, p. 123961)[2],[3]. Their long term performance depends on their insulation system which is made of a paper and a liquid insulator. In order to improve the environmental impact of these insulators, several national and international policies under pressure from environmentalists are increasingly demanding the use of biodegradable liquid dielectrics (I. Fofana, 2013, pp. 13-25), (R. Madavan, S. Kumar, and M. W. Iruthyarajan, 2018 pp. 30-36) [4],[5]. This has triggered a particular interest in bio-insulators in the transformer liquid dielectric manufacturing industry(U. Khaled and A. Beroual, 2019, pp. 60594-60601)[6]. Liquid dielectrics based on natural esters have been the most investigated dielectrics for more than a decade in order to highlight their physicochemical, dielectric and thermal properties (J. Jacob, P. Preetha, and S. T. Krishnan, 2020, pp. 33-43)[7]. Most of these esters are extracted from natural edible oil seeds, which is not environmentally friendly. These liquid dielectrics based on natural esters are the result in some cases of a transformation of natural oils into methyl esters (E. TchamdjioNkouetcha, G. MengataMengounou, A. MoukengueImano, 2019, p. 1), (G. MengataMengounou, A. MoukengueImano, and J. Vardamides, 2016, pp. 210-212)[8],[9]. In spite of their good physicochemical and dielectric properties, their biodegradability, these bio-insulators present some limits in particular their pour point is generally included between 83,46 and 126,17 according to the temperature, their fast rancidity which is shown by an index of high acidity higher than 2,4±0,6 (G. MengataMengounou, A. MoukengueImano, and J. Vardamides, 2016,pp. 210-212), (G. Dombek and Z. NADolNy, 2017)[9][10]. In addition, the BDV of these bio esters, although acceptable with regard to the standards (ASTM D1816, ASTM D877, IEC 60156…), remains lower than that of mineral oils in several cases(] D. Martin and Z. Wang, 2008,pp. 1044-1050), (G. D. Peppas et al, 2016pp. 644-652) and (A. Beroual, H. B. Sitorus, R. Setiabudy, S. Bismo, 2018,pp. 1831-1836)[11],[12],[13].

In an effort to reduce not only the weight and size of transformers, many transformer manufacturing industries are working to leverage technological developments to achieve this goal(R. Madavan, S. Kumar, and M. W. Iruthyarajan, 2018 pp. 30-36)[5]. This improvement requires the physicochemical, dielectric and thermal properties of the bio-insulators serving as the main cooling circuit. For more than ten years, work aiming to find solutions in this direction has opted for the addition of NPs in insulating liquids (S. U. Choi and J. A. Eastman, 1995), (] R. Karthik, T. S. R. Raja, and R. Madavan, 2013,pp. 2725-2733) and (R. Madavan and S. Balaraman, 2017, pp. 437-444)[14][15][16]. First used by Choi et al, the term nanofluid which refers to the mixture of a fluid and NPs; this addition was intended to improve the heat transfer rate of an insulator by the dispersion of different metal oxide nanoparticles (S. U. Choi and J. A. Eastman, 1995)[14]. Since then, several studies on the possibility of improving the physicochemical, dielectric and thermal performances of natural esters by adding NPs which can be conductive (iron NPs) or semiconductive (copper or zinc NPs) have been initiated. This addition of NPs is done according to two main methods, namely the one-step method and the two-step method (N. A. Mohamad, N. Azis, J. Jasni, M. Z. A. Ab Kadir, R. Yunus, and Z. Yaakub, 2019, p. 1605), (J. Jacob, P. Preetha, and S. T. J. I. N. Krishnan, 2020, pp. 33-43)[17][18]. The one-step method consists of directly synthesizing the NPs in the base esters before any other possible operation. This method is not recommended for large concentrations of NP and requires sophisticated equipment that is not always available (N. A. Mohamad, N. Azis, J. Jasni, M. Z. A. Ab Kadir, R. Yunus, and Z. Yaakub, 2019, p. 1605), (J. Jacob, P. Preetha, and S. T. J. I. N. Krishnan, 2020, pp. 33-43)[17],[18]. In the two-step method, the NPs are synthesized outside of the base esters and then dispersed into these esters by the sonication process (N. A. Mohamad, N. Azis, J. Jasni, M. Z. A. Ab Kadir, R. Yunus, and Z. Yaakub, 2019, p. 1605), (J. Jacob, P. Preetha, and S. T. J. I. N. Krishnan, 2020, pp. 33-43) and (] W. Saenkhumwong and A. Suksri, 2015, pp. 175-178)[17],[18],[19]. This second method seems to be the simplest and does not require the use of sophisticated equipment like the one-step method. However, it should be noted that the nanofluid samples obtained are not always stable. To overcome this lack due to the agglomeration of nanoparticles, several solutions are successfully explored in order to reduce this agglomeration in particular of surfactant during the sonification phase such as oleic acid or carboxilic acid and the use of dispersants (J. Jacob, P. Preetha, and S. T. Krishnan, 2020, pp. 33-43), (V. A. Primo, B. García, D. Pérez, and J. C. Burgos, 2019, pp. 1-4)[7, 20]. The addition of ZnO NPs to natural esters has already been the subject of several works. Several works have focused on the effect of ZnO NPs on biosolids based on sunflower oil, rapeseed oil, palm oil(R. Madavan and S. Balaraman, 2017, pp. 437-444), (W. Saenkhumwong and A. Suksri, 2017, pp. 148-153) (I. Fernández, R. Valiente, F. Ortiz, C. J. Renedo, and A. Ortiz, 2020,p. 692)and(M. Srinivasan, U. Ragupathy, K. Sindhuja, and Raymon, 2016, pp. 1000-1007) [16],[21],[22],[23]. Some of these works have used ZnO NPs in powder and liquid form to make a comparative study (M. Srinivasan, U. Ragupathy, K. Sindhuja, and Raymon, 2016, pp. 1000-1007) [23]. These different studies show that the addition of ZnO nanoparticles improves the breakdown voltage of natural esters. The contribution of zinc nanoparticles on the thermal, dielectric and physico-chemical properties of MEPKO remains poorly understood. To this end, the present work investigates the impact of zinc nanoparticles (ZnO) on the BDV and the IA of MEPKO.

2. SETUP AND PROCEDURE

2.1 Methyl Eters OF PALM KERNEL OIL (MEPKO)

The process of obtaining MEPKO is based on the extraction, degumming and transesterification of crude palm kernel oil (Figure 1a). The extraction is done from the palm nuts (Kernel ElainesisGuinesis) heated, crushed and pressed. In order to reduce the acidity of this crude oil, a refining operation is carried out, also called degumming. Once the refined oil (Figure 1b) is obtained, transesterification is carried out to obtain the MEPKO (Figure 1c). The degumming operation is done after determining the acidity index of the crude oil. The crude oil obtained having presented an acidity of 12.52mg KOH /g, requires 47.5g of NaOH dissolved in 500ml of distilled water to make the acidity to 0.561mg koh /g. The transesterification consists in breaking the double and triple bonds of fatty acids existing in the oil. For this, we take for 100g of refined oil, 2g of sodium potassium (KOH) and 20g of methanol that we shake to homogenize the mixture before adding the 100g of oil. The mixture is left in agitation at 60°C for 120 minutes. Once the 120 minutes have passed, the mixture obtained is left in the separating funnel for one hour in order to separate the glycerol from the MEPKO. [8, 9]. In order to remove possible impurities after transesterification, the MEPKO are washed until a neutral pH is reached; then dehumidified and degassed.

a) b) c)

Fig.1 *a) Palm Kernel Oil b)Rafined Palm Kernel* c) Methyl Esters of Palm Kernel Oil

2.2 Préparation of nanofluids

The samples are obtained after dispersion of the NPs (ZnO) in the MEPKO. Three concentrations are taken into account, namely 0.10%, 0.15% and 0.20%. The MEPKO and the NPs are dehumidified in an oven at 80°C for 24 hours. Once this step is done, we move to agitation with a magnetic stirrer of 1000 rpm;for one hour before launching the homogenization process by ultrasound. homogenization is made by an ultrasonic (UP-2505) of 150 W of power with a 25KHZ of frequency presented in figure 2 during two hours; as it is made in other works (J. Jacob, P. Preetha, and S. T. Krishnan, 2020, pp. 33-43), (R. Madavan and S. Balaraman, 2017, pp. 437-444)[7],[16]. The obtained nanofluid samples are once again placed on a magnetic stirrer for 45 minutes and dehumidified for 24 hours at 80°C before any possible testing. This protocol for obtaining the samples is illustrated in Figure 3. The samples (E2, E3 and E4) are presented in figure 4. The basic properties of the nanoparticles used and the MEPKO are presented in Tables 1 and 2, respectively.

Fig. 2*.Sonification Process*

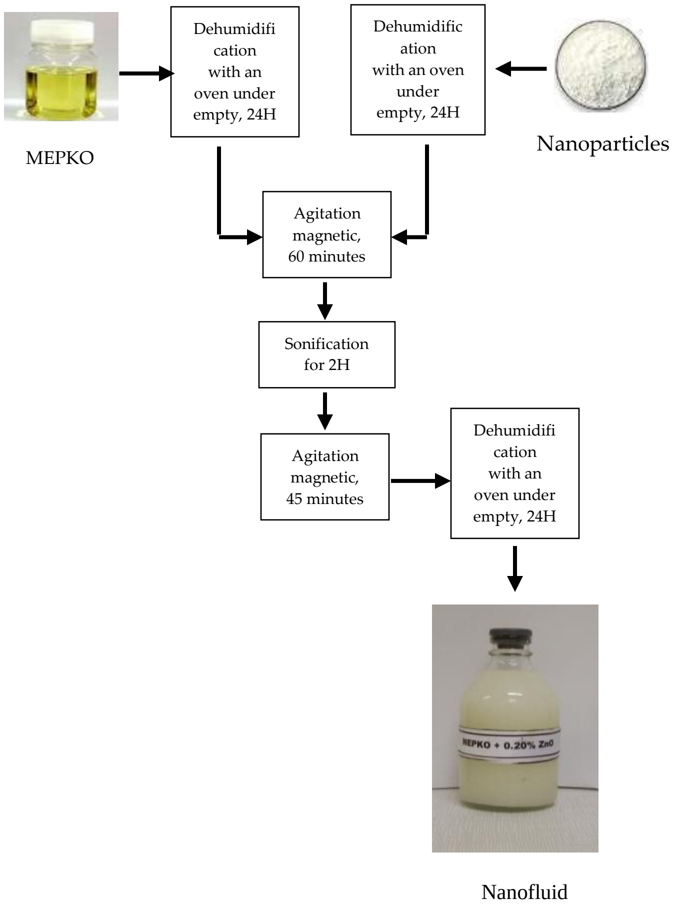

***Fig. 3**: Protocol for obtaining nanofluid samples*

a) b) c)

***Fig. 4a)** E2 (MEPKO + 0, 10%ZnO) b) E3 (MEPKO + 0, 15%ZnO) c) E4 (MEPKO + 0, 20%ZnO)*

***Fig. 5**. Zinc Nanoparticles*

***Table 1.** Basics properties of ZnO*

ZnO	
Size (nm)	30-200nm
Appaerancecolor	White
Density (g/cm3)	5.1
Solubility water	insoluble
Boiling Point	2360°C
fusion point	1975°C
Molecular mass	81.41g/Mol

***Table 2.** Basics properties of MEPKO [9]*

Properties	Standard	Unity	MEPKO
Aspect CEI 296	Aspect CEI 296	-	Clear
Density at 20 °C ISO 12185	Densité à 20 °C ISO 12185	-	0,864
Viscosity at 40°C	ISO 3104	mm2/s	4,46±0,11
Acidity Index	ISO 660	mgKOH/g	2,4 ± 0,6

2.3 Breakdown Voltage (BDV)

In order to compare the results, breakdown voltage tests for each sample are performed before and after addition of the NPs. This measurement is done by means of a Insulating oil tester presented in Figure 6 integrating several standards (ASTM D1816, ASTM D877, IEC 60156...). The standard used for our experimentation is the D1816 standard with an inter-electrode distance of 1mm. Table 3 below presents the main properties of the D1816. Knowing that a single test performs five snaps, five tests were performed for each sample, i.e. twenty-five snaps. With a confidence interval of 1, the value of the error was determined using the following mathematical formulae:

$$\mathbf{U(k)} = \frac{\sigma}{\sqrt{n}} * \mathbf{k} \tag{2}$$

$$\mathbf{Error} = [\mathbf{BDV} + \mathbf{U(k)}] - [\mathbf{BDV} - \mathbf{U(K)}] \tag{3}$$

Where n represents the number of breakdowns performed, K the confidence interval, U(k) the margin of error of the confidence intervalet σ the standard deviation of the measurement.

***Fig. 6**. Insulating oil tester*

2.4 Acidity Index

The acidity Index of a liquid dielectric for a power transformer is an important factor because it determines the level of deterioration of the liquid dielectric. In order to determine it based on the IEC 296 standard, a titration was done. For this purpose, an alcoholic KOH of concentration [0.1n] is prepared (250ml ethanol with 1.4g KOH), 10g oil and 80ml ethanol. The color indicator used is phenolphthalein. We then take the volume of KOH solution elapsed during the turn before calculating the AI from the following mathematical formulae:

$$\mathrm{IA} = 5{,}6\left(\frac{\mathrm{V_{koh}}}{\mathrm{M_h}}\right) \qquad (1)$$

Where AI is the Acid Number (mg Koh/g), VKOH is the Volume of KOH used (ml) and mh (g) is the mass of oil used. This test is performed 3 times for each sample to determine the average volume to get the acid value of the sample. All this is done in order to minimize the margin of error in our measurements.

3. RESULTS AND DISCUSSION

3.1 Impact of ZnO on the AI of MEPKO

From the results of the various tests presented in Table 3, we can see that the addition of ZnO to the esters significantly changes the AI. For the 0.10% concentration, there is an increase from 0.337 mg KOH/g to 1.403 mgKOH/g, a 320% increase. For the concentration of 0.15%, there is an increase from 0.337 mg KOH /g to 0.954 mg KOH /g; that is to say an increase rate of 183%. For a concentration of 0.20%, the AI varies from 0.337 mg KOH /g to 0.729 mg KOH /g, an increase of 116%. Figure 7 below shows the evolution of the AI as a function of these concentrations

***Table 3**: AI values with the addition of ZnO NPs*

Acidity Index Tests			
Samples	Vmoy (ml)	Coef (g/Mol)	AI (mg koh/g)
MEPKO (E1)	0,6	0,561	0,337
MEPKO + 0,10%ZnO (E2)	2,5	0,561	1,403
MEPKO + 0,15%ZnO (E3)	1,7	0,561	0,954
MEPKO + 0,20%ZnO (E4)	1,3	0,561	0,729
MEPKO + 0,20%ZnO (E4)	1,3	0,561	0,729

E1 : MEPKO (Methyl Esters of Palm Kernel Oil)
E2 : MEPKO + 0,10% de ZnO
E3: MEPKO + 0,15% de ZnO
E4 : MEPKO + 0,20% de ZnO

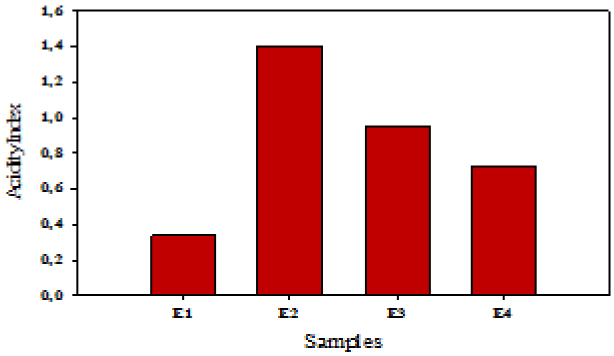

***Fig. 7**. Influence of ZnO NPs on the AI of MEPKO*

It can be seen here that the concentration of 0, 10% results has a high AI compared to that of MEPKO. However, as the concentration increases, there is a slight decrease in this value.

3. 2 Impact of ZnO on the BDV of MEPKO

The breakdown voltage of a dielectric is defined as the minimum electrical voltage that makes a dielectric portion conductive. The dielectric strength of an insulator depends very strongly on this voltage. For our tests, we use the ASTM D1816 standard with an inter-electrode distance of 1mm through the HYYJ-502 INSULATING OIL TESTER. The results presented in Table 4 show that for the concentration of 0.10%, the BDV decreases from 48.6Kv to 45.1Kv, i.e. a decrease of 8%. The evolution of the BDV for the 0.15% concentration is from 48.6Kv to 47.24Kv; a decrease of 3%. For the concentration of 0.20%, we have a variation of 48.6Kv to 52.98Kv or a percentage increase of 9%.

***Table 5:** Breakdown voltages of the different samples*

Breakdown voltage tests						
Samples	Mean Value	σ	n	K	U(K)	Error
MEPKO (E1)	48,6	4,18	25	1	0,836	2,16
MEPKO + 0,10% ZnO (E2)	45,1	3,34	25	1	0,668	1,34
MEPKO + 0,15% ZnO (E3)	47,24	1,98	25	1	0,396	0,22
MEPKO + 0,20%ZnO (E4)	52,98	2,72	25	1	0,544	0,792

E1 : MEPKO (Methyl Esters of Palm Kernel Oil)
E2 : MEPKO + 0,10% de ZnO
E3: MEPKO + 0,15% de ZnO
E4 : MEPKO + 0,20% de ZnO

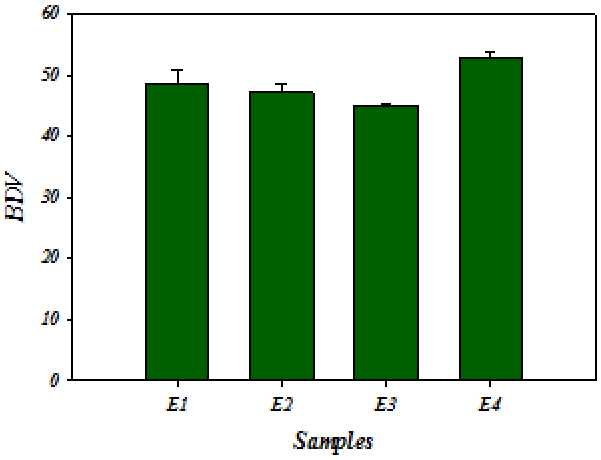

***Fig. 8**. Influence des NPs de ZnO sur la BDV des MEPKO*

Figure 8 above shows that the only increase is the one obtained with the 0.20% concentration. The other two concentrations namely 0.10% and 0.15% cause a decrease in the BDV value.

4. CONCLUSION

In this paper, the impact of ZnO nanoparticles in MEPKO was analyzed. With regard to the BDV, an improvement is observed. Thus, it is observed that for the concentration of 0.10%, the BDV from 48.6Kv to 45.1Kv. The decrease in BDV for the concentration of 0.15% is from 48.6Kv to 47.24Kv. For the 0.20% concentration, there is an increase from 48.6Kv to 52.98Kv. Regarding the acidity index, for the concentration of 0.10%, there is an increase from 0.337 mg KOH /g to 1.403 mg KOH /g, an increase of 320%. For the 0.15% concentration, there is an increase from 0.337 mg KOH /g to 0.954 mg KOH /g; that is, an increase rate of 183%. For a concentration of 0.20%, the AI varies from 0.337 mg KOH /g to 0.729 mg KOH /g, an increase of 116%. The analysis of these results allows us to notice that the addition of NP in EMHP improves the BDV for the concentration of 0.20% of ZnO. This is not the case for the AI which on the contrary deteriorates with increasing value.

5. CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper

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6. ACKNOWLEDGEMENT

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