Comparison of Statistical Breakdown Voltages in Persea Americana Oil and Mineral Insulation Oil and their Mixtures

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Abstract

This paper presents a comparative analysis of the statistical Breakdown Voltage (BDV) in a plant based oil, Persea americana oil (PAO), mineral insulation oil (MIO) and their mixtures.Two types of PAO are tested, that is extra virgin PAO (EVPAO) and refined PAO (RPAO). PAO and MIO and the oil mixtures (namely 50%RPAO+50%MIO and 50%EVPAO+50%MIO) are subjected to AC voltages. At least ten tests were carried out for each sample as per IEEE guide for the statistical analysis of electrical insulation breakdown data (IEEE 930 or IEC 62539). The statistical analysis shows that the data for AC breakdown voltages of RPAO, EVPAO, MIO and the oil mixtures obey to the normal distribution law. This is proved using Shapiro-Wilk test, skewness and kurtosis values. It is shown that the average AC breakdown voltage of RPAO is higher than that of MIO. It also observed that AC mean breakdown voltage of RPAO is higher than that of oils mixture (50%RPAO+50%MIO) and MIO. (50%RPAO+50%MIO) BDV is higher than that of MIO. AC mean breakdown voltage of EVPAO and MIO mixture is the lowest one. Thus PAO constitutes a potential liquid for replacing mineral oil in high voltage equipment.

Keywords—Breakdown voltage, Statistical analysis, Persea americana oil (PAO), Mineral insulation oil (MIO), PAO/MIO mixtures, Refined Persea americana oil (RPAO).

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1. INTRODUCTION

Plant based oil use in electrical equipment can be traced as far as in 1892. However, their continued use in electrical equipment suffered a setback as their thermal-oxidative stability was inferior to that of mineral insulation oil (MIO) (McShane C.P, .2002).

Pro-green energy policies, safety and increasing tight regulations on the environment in recent years have encouraged the use of plant-based oils for transformer applications. Plant-based oils are a suitable replacement to MIO because of their many merits such as biodegradability and high flash points (Gnanasekaran D. et al,2018) and (Khan I, et al, .2006). Use of plant-based oils as substitutes for mineral insulation oil(MIO) in high voltage filled equipment has become a reality today. Some commercial plant based oils such as FR3 and BIOTEMP fluids are presently used in distribution transformers and even in high capacity power transformers.

Plant-based oils are made of triglyceride whichconsists of glycerol and fatty acids as shown in Figure.1 (McShane C.P, .2002) and (McShane C.P, .1999).The fatty acids determine the chemical and physical properties of plant-based oils (Viertel J.et al, .2011). For example, the pour point and melting points can be predicted by looking at the percentage of the unsaturated fatty acids in a particular plant oil. Increase of the unsaturated fatty acids content leads to decrease of pour point and melting point (Abdelmalik A.A, et al, .2014). Different plant based oils such as sunflower and canola have been explored for application in transformers (Jian L, et al, .2007) and (Adeolu O, et al, .2014).

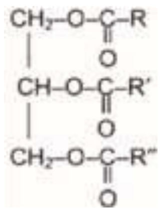

Fig.1. Triglyceride structure.

Perseaamericana oil (PAO) is a new type of vegetable oil that has been proposed as a dielectric insulating fluid in transformers(Makaa B, et al, .2019). Two types have been investigated; extra virgin *Perseaamericana* oil (EVPAO) and refined *Perseaamericana* oil (RPAO).Table 1 shows the investigated properties for both EVPAO and PAO (Makaa B, et al, .2019).

In this paper, a detailed statistical analysis of the breakdown voltage (BDV) of RPAO, EVPAO, MIO and their mixtures (namely 50%RPAO+50%MIO and 50%EVPAO+50%MIO) is carried out. When replacing MIO by PAO in an installed transformer, the mixing of PAO and MIO is inevitable since the draining process still leaves oil in the spaces between the windings and the bottom of the tank. Therefore it is important to examine the effect of the oil mixture on the BDV. Breakdown voltage results are analyzed using a statistical method, that is, the distribution normal law. Statistical analysis is performed by using SPSS 23.0.

2. METHODOLOGY

The objectives of this investigative research were achieved by carrying out the BDV tests on PAO and comparing the results with those of MIO. The samples that were investigated included both food grade extra virgin(EVPAO) and refined(RPAO)Persea *americana* oil. The experiments were carried out at Sigma Test and Research Centre laboratory.The room (lab) temperature was 27^0C and relative humidity was 65%.In this research, the measurements were performed based on IEEE, IS and IEC standards in accordance with the equipment available at Sigma Test and Research Centre laboratory. The BDV measurements were performed in sphere-sphere electrode system with 12.5mm of diameter, 2.5±0.05mm of distance in accordance with IEC60156 specifications.

AC high voltage is supplied by a high voltage test transformer 100kV-50Hz. The experimental results used in the analysis are the maximum AC voltage values. The voltage is continuously applied with a rate of rise 2.±0.05kV/s until breakdown occurs. The rest time between each test was 10minutes for PAO and 5 minutes for MIO. 10 tests were carried out for each sample. IEC 60156 standard requires 6 measurements only for analysis (IEC 60156:2018).

TABLE 1. PHYSICOCHEMICAL & ELECTRICAL PROPERTIES OF EVPAO, RPAO, AND MIO.

Property	Method	RPAO	EVPAO	MIO	Requirement for MIOIS:335-1993/ (IEEE.C57.106)/ ASTM D 3487
Relative Density at 15°C [g/cm^3]	ASTM Dl298	0.903	0.903	0.825	0.89(Max)
Breakdown Voltage (BDV)(Kv)	ASTM D 1816 (a)/IEC 60156	74	36	65	35
Dielectric Dissipation Factor (DDF)	ASTM Std. D 924	0.33	1.86	6.92	0.4(Max)
Resistivity(at 27°C), ohm-cm)	ASTM D1169-64	$7.35x10^{12}$	$0.28x10^{12}$	$0.94x10^{12}$	$1500 x 10^{12}$ (Min)
Resistivity(at 90°C), ohm-cm	ASTM D1169-64	$2.56x10^{12}$	$0.51x10^{12}$	$0.48x10^{12}$	$35 x 10^{12}$ (Min)
Neutralization Number (NN)mg KOH/g	ASTM D664-04	0.073	1.49	0.073	0.4(Max)
Flash Point,°C	ASTM D93 - 18	310	142	156	140(Min)
Pour Point,°C	ASTM D97	-7	-4	-11	-6 (Max)
Water Content(ppm)	ASTM.D1533	136.05	924.71	88.77	50(Max)
Appearance	ASTM D1500	Clear and transparent	With suspended sediments	Clear and transparent	Clear / No Particulates

Viscosity Test @ 27 °C, cSt	ASTM D 445-72	45.66	52.03	10.46	12.0(Max)
Viscosity Test @ 40 °C, cSt	ASTM D 445-72	35.58	38.54	8.15	27(Max)
Interfacial Tension(IFT) @27°C,N/m.	ASTM D 971-50	0.048	0.051	0.046	0.4(Min)

3. RESULTS AND DISCUSSIONS

Figure 2 shows the BDV results for RPAO, EVPAO, MIO and the mixtures. It appears that the values of breakdown voltages are scattered around the mean of the average BDV.The average BDV of RPAO is slightly greater than that of MIO. The distribution frequency of AC breakdown voltage appears to obey a normal distribution as shown in figures 4 to 8.To identify whether the distribution of the data obtained is normal, one applies Shapiro-Wilk (Shapiro S. S.,et al, 1965) tests to calculate W-value and P-value (Tables). In this statistical analysis, normal distribution is considered with a significant level test of 5% (α = 0.05). P-value is the probability of making mistake that the null hypothesis is rejected. If P-value is higher than the significant level (α =0.05), one accepts null hypothesis that the sample data follows a statistical distribution. It appears from this table thatall sample data tested are accepted.

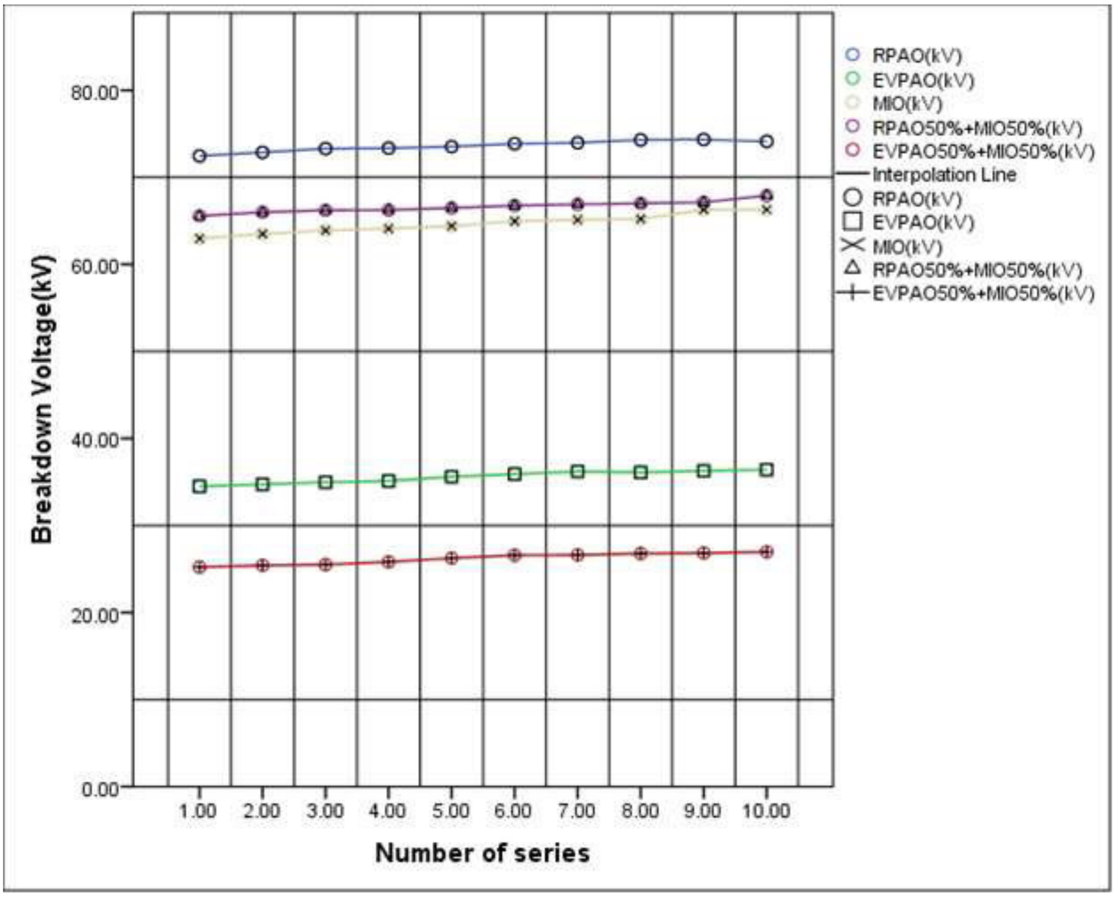

Fig. 2.AC Breakdown voltage scattering of RPAO, EVPAO, MIO and the Oil Mixtures.

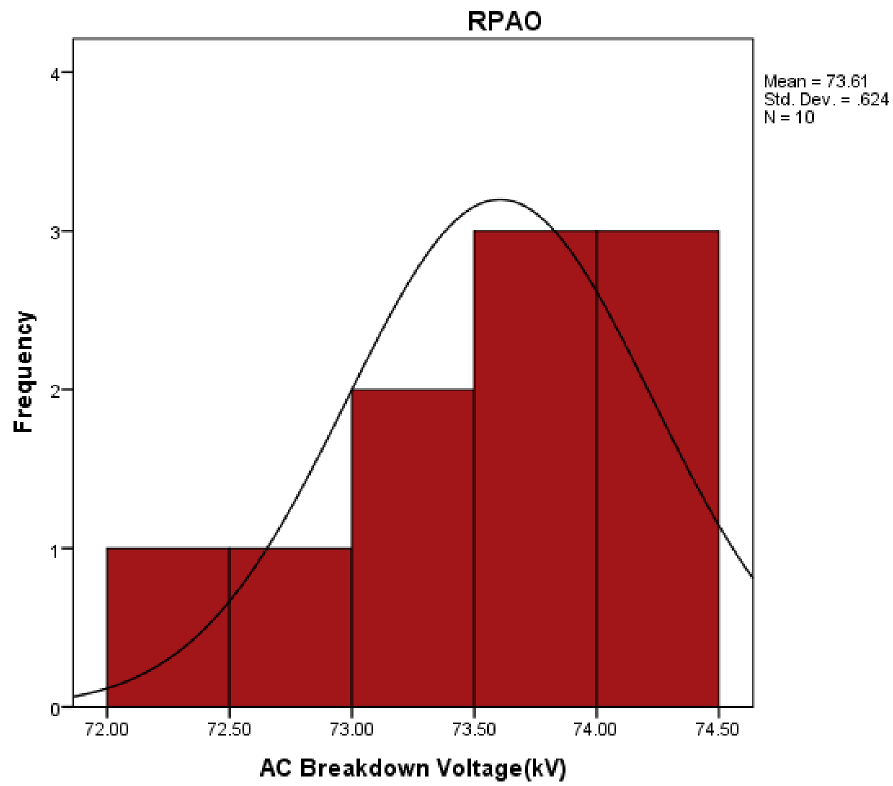

Fig.3.RPAO BDV Histogram.

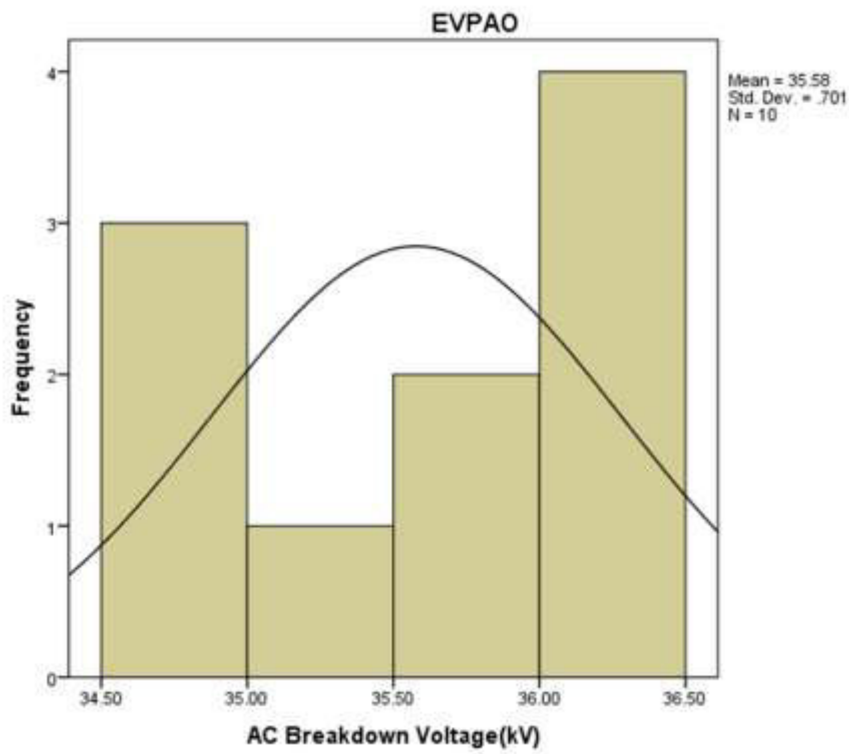

Fig.4.EVPAO BDV Histogram.

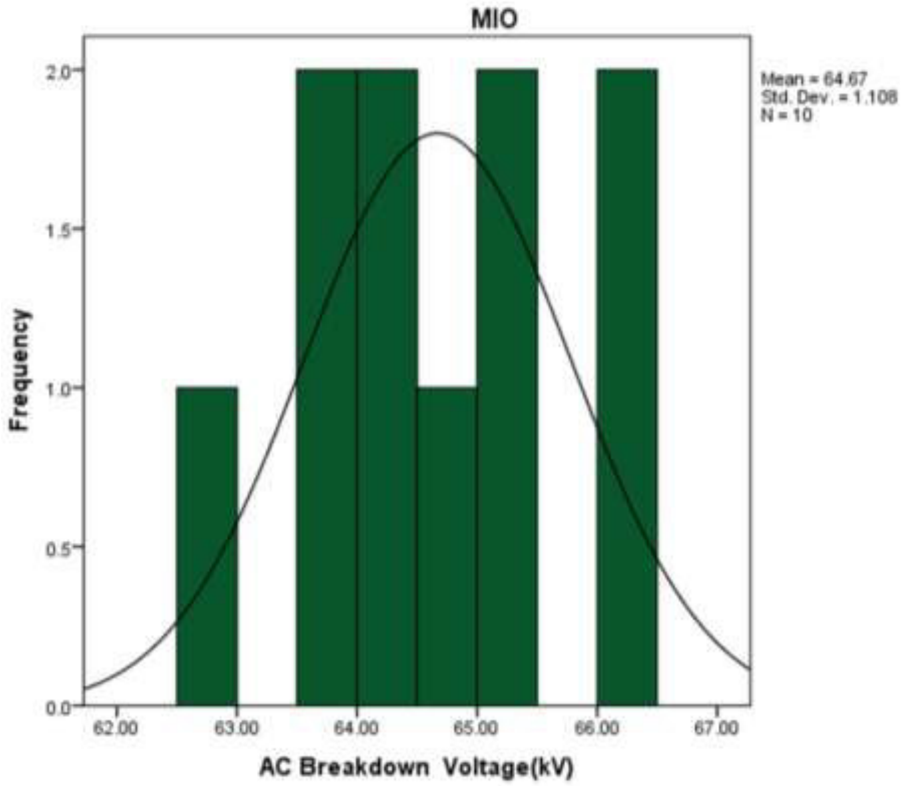

Fig.5.MIO BDV Histogram.

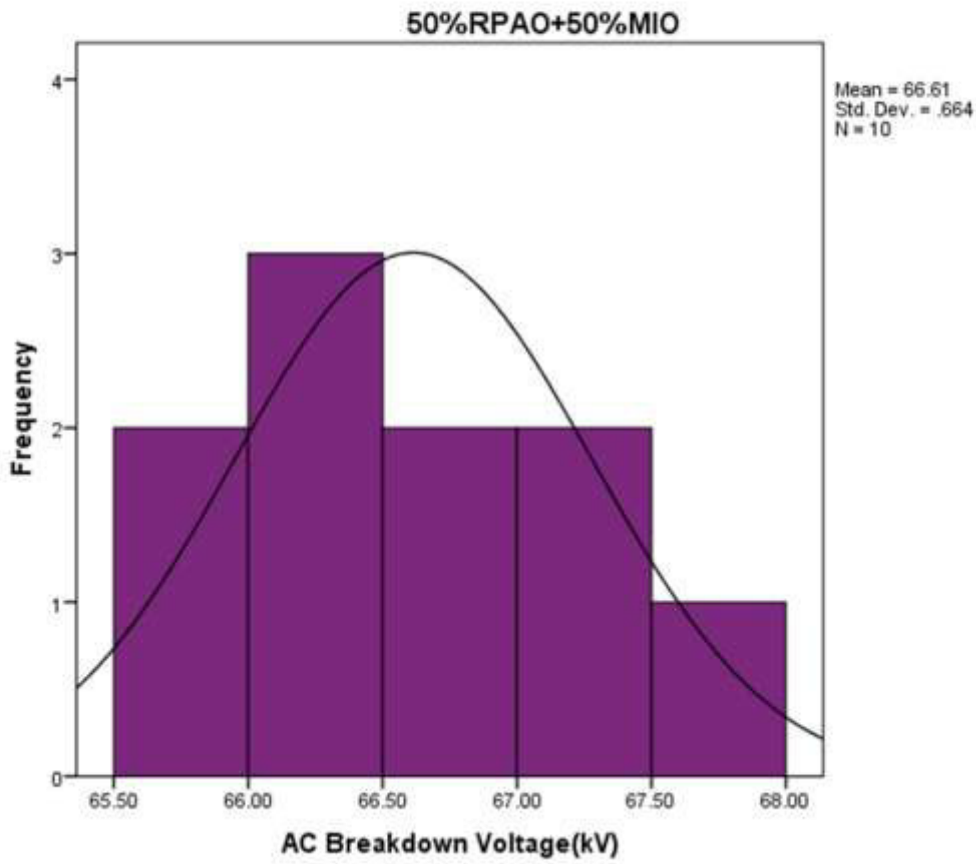

Fig.6.50%RPAO+50%MIO BDV Histogram.

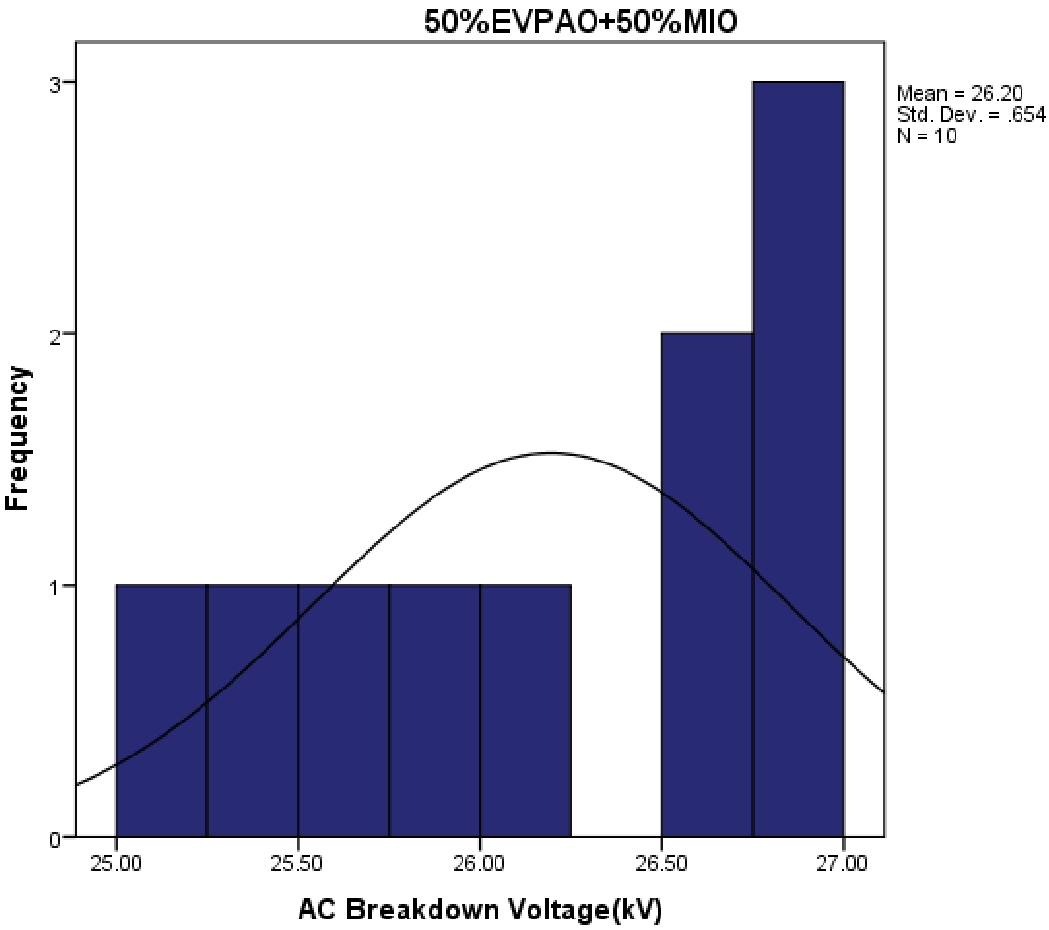

Figure.7.50%EVPAO+50%MIO BDV Histogram.

TABLE 2.HYPOTHESIS TEST OF CONFORMITY TO NORMALDISTRIBUTION OF AC BREAKDOWN VOLTAGE

Sample	**W**	**p-value**	**Conformity to Normal distribution**
RPAO	0.942	0.574	accepted
EVPAO	0.905	0.248	accepted
MIO	0.956	0.740	accepted
50%RPAO+50%MIO	0.981	0.969	accepted
EVPAO50%+MIO50%	0.891	0.173	accepted

The skewness and kurtosis values obtained from the SPSS program are presented in Figure 8.From kurtosis and skewness values, one can determine whether a distribution frequency is normal. In a normal distribution, the kurtosis and skewness values are 0(zero). The kurtosis and skewness values indicate the deviation from normal. A distribution with positive kurtosis has many scores in the tails (a so-called heavy-tailed distribution) and is pointy. This is known as a leptokurtic distribution (Viet-Hung Dang, et al, 2012). A distribution with negative kurtosis is relatively thin in tails (has light tails) and tends to be flatter than normal. The distribution is called platykurtic (Viet-Hung Dang, et al, 2012).

A positive skewness value implies that the frequent scores are clustered at the lower end and the tail points towards the higher or more positive scores. If the skewness value is negative (negative skewed), it means the frequent scores are clustered at the higher end and the tail points towards the more negative scores.

The skewness values of the breakdown voltage of MIO and RPAO50%+MIO50% are positive. This indicates a pile-up of scores to the left of distribution. The skewness values of RPAO, EVPAO and EVPAO50%+MIO50% are negative. This indicates that a pile-up of scores on the right side of the distribution.

Except for the oil mixture RPAO50%+MIO50%, the kurtosis values for all tested values are negative. This implies that all distributions are platykurtic, except for the distribution of oil mixtures RPAO50%+MIO50%.

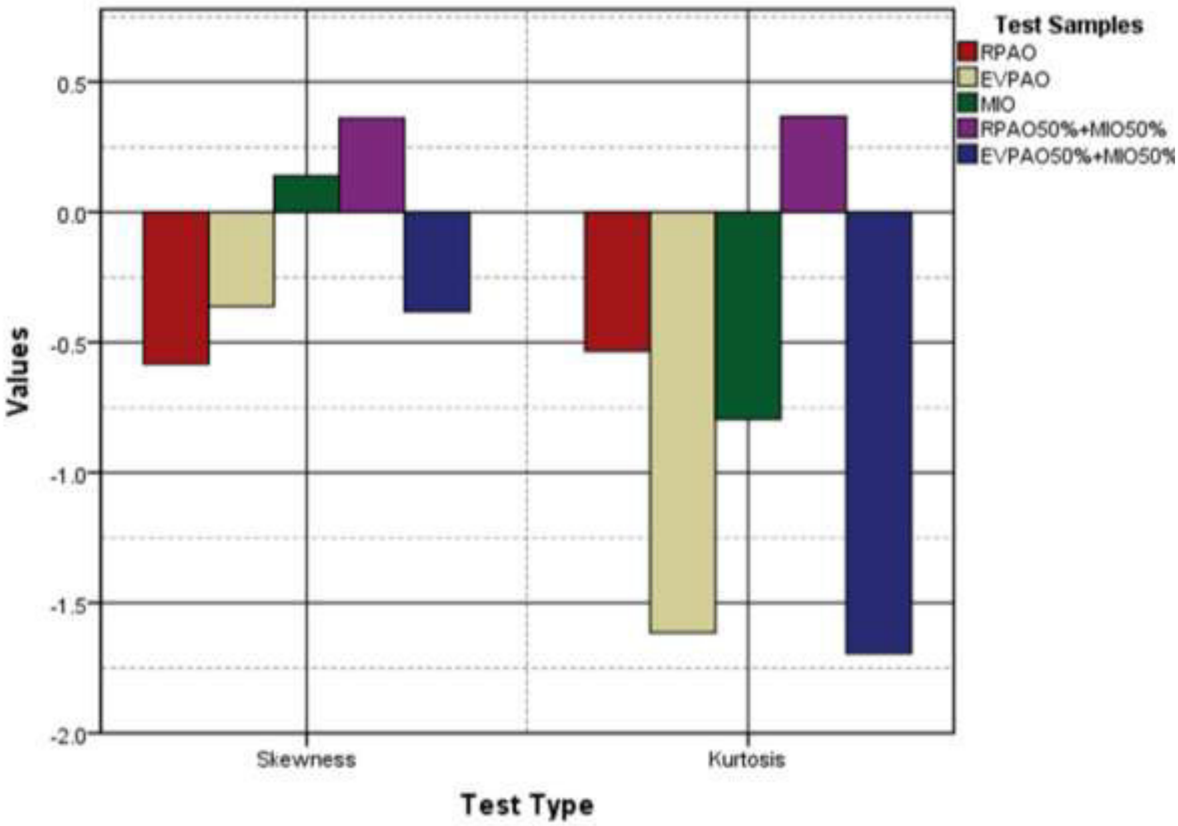

Fig.8.Skewness and kurtosis of normal distribution of AC breakdown voltage of tested oils/mixtures.

Figure 9 shows the average value and the standard deviation of all tested oils under AC voltage. It can be observed that the AC mean breakdown voltage of RPAO is highest of the all the samples tested. The AC mean breakdown voltage of the mixture EVPAO50%+MIO50% is the lowest. The AC mean breakdown voltage of the mixture RPAO50%+MIO50% is higher than that of MIO. This indicates that there is no problem in the event that RPAO (or PAO) is mixed with the MIO during the replacement process in an already installed transformer.

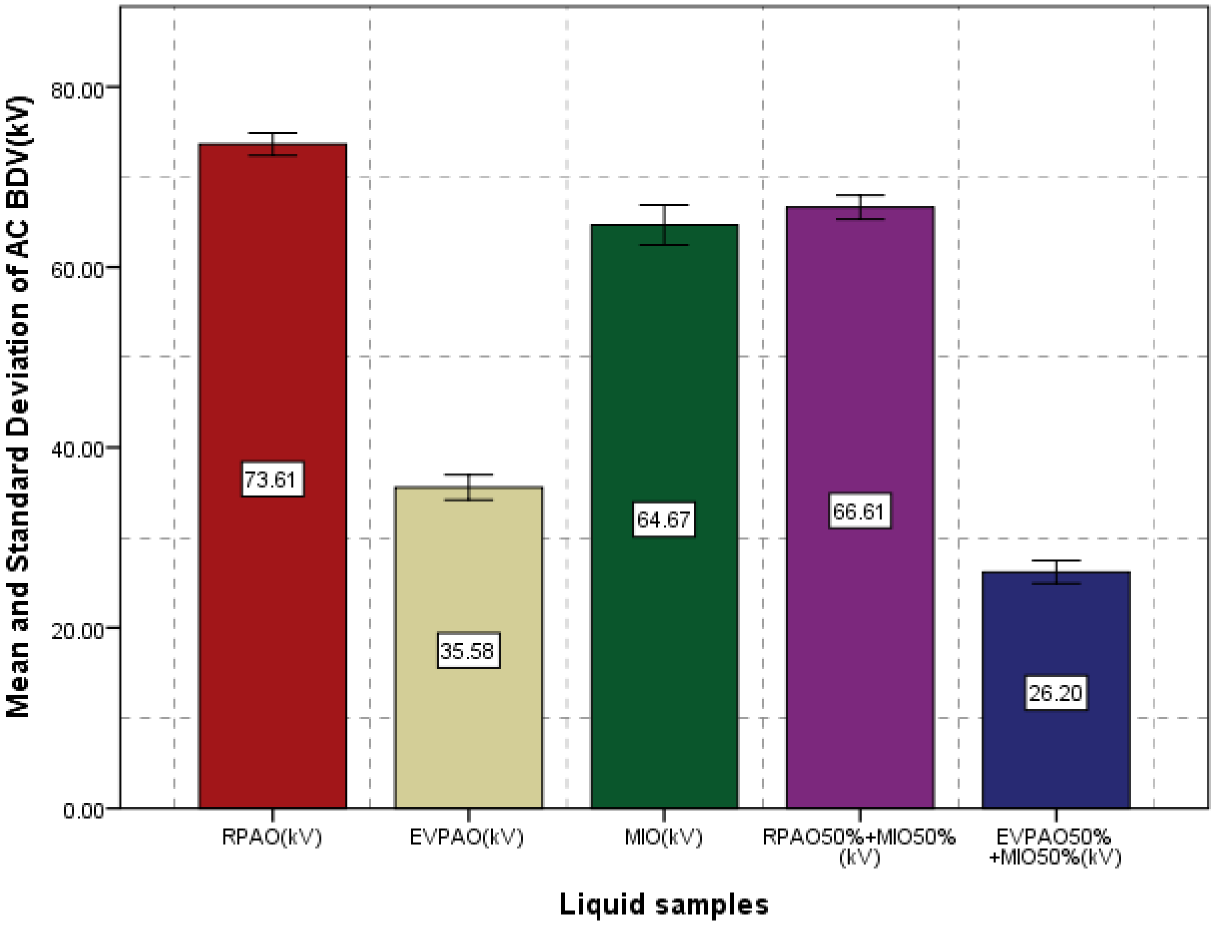

Fig. 9. Mean and standard deviations of AC breakdown voltage of tested oils/oils mixture

4. CONCLUSION

This paper shows that the BDV of RPAO, EVPAO and MIO measured based on IEC 60156 standard follows a normal distribution. The average BDV of RPAO (PAO) is higher than that of MIO. It also appears that the BDV of RPAO is higher than that of the mixture RPAO50%+MIO50%. The AC mean breakdown voltage of the mixture EVPAO50%+MIO50% is the lowest.

The statistical analysis of experimental data shows that the distribution frequency of AC breakdown voltages follows normal distribution as evidenced by Shapiro-Wilk test, Skewness and kurtosis values.

We also note that the physical-chemical an electrical properties of PAO generally comply with IEEE c.57.147 and IS: 335-1993except for pour point that should be less than-14^{0}C. This can be improved by adding the necessary additives to improve the pour point.

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