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Statistical Analysis of AC Dielectric Strength for Palm Oil under the Influence of Moisture

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ABSTRACT

This paper presents a statistical study on the AC Breakdown Voltage (BDV) of Refined, Bleached and Deodorized Palm Oil (RBDPO) olein under the influence of moisture. Different moisture contents of the RBPDPO were prepared by drying the RBDPO in the oven at different time intervals. The AC BDV test of RBDPO was performed whereby the distance between 2 electrodes was set to 1 mm. The statistical analyses of AC BDV data for RBDPO were carried out based on normal, lognormal and Weibull distributions. It was shown that as the moisture content increased, the AC BDV of RDBPO decreased exponentially. Statistical analyses revealed that the AC BDV data with different moisture contents had platykurtic distributions. Moisture could influence the skewness of the distribution whereby the tail shifted from right to left as the content increased. At different moisture contents of RBDPO, most of the AC BDV data of RBDPO could be represented by Weibull distribution.

Keywords: AC breakdown voltage, moisture, palm oil, statistical distribution

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INTRODUCTION

Among the main insulation materials in transformers is Mineral oil (MO). MO has an excellent electrical insulation and cooling properties, and it could act as an information carrier to determine the condition of transformers (Heathcore, 2007). It has been extensively used for decades due to its good performance to provide the necessary insulation to transformers (Martins, 2010; Oommen, 2002).

However, MO has several issues such as low fire/flash points and moisture tolerance (Tenbohlen & Koch, 2010). It has poor biodegradability, and it could cause contamination issues if serious spills occur in the soils and waterways (Mohamad et al., 2015). In addition, MO is a non-renewable source (Azis et al., 2014). Recently, the interests on environmental considerations in electrical industries are increasing which prompt for serious efforts to seek alternatives for MO.

Several types of Vegetable Oil (VO) have been identified as viable alternatives for MO whereby extensive laboratories experimental works and in-services testing have been carried out previously (Rafiq et al., 2015). Palm Oil (PO) is among the VOs that have been considered as alternative of MO for dielectric insulating liquid application (Mohamad et al., 2014). Different types of POs have been investigated where promising results have been obtained (Suwarno et al., 2003). Refined, Bleached and Deodorized Palm Oil (RBDPO) has been established as one of the promising POs which can be used as dielectric insulating fluid in transformers (Suleiman & Muhamad, 2011). RBDPO is environment friendly and it has high fire safety as compared to the MO (Aditama, 2005; Kiasatina et al., 2011). It is widely available in Malaysia and its characteristics such as biodegradability and non-toxicity are similar to other types of VO (Azis et al., 2014).

Previous studies have shown that the AC Breakdown Voltage (BDV)s of the MO and VO could be affected by the moisture (Takaaki et al., 2008). Previous study on MO showed that the AC BDV could decrease by 78% as the moisture increased from 12 ppm to 41 ppm (Suwarno & Prakoso, 2015). The study had shown that the AC BDV of MO maintained almost unchanged at low level as the relative water content increased higher than 50% (Suwarno & Prakoso, 2015). Wang & Wang (2008) had shown that the highest percentage of decrement for AC BDV for MO was 68% and a decrement trend was observed as the relative humidity increased from 3 % and 98%. Martin & Wang (2006) revealed that the AC BDV of MO decreased from 29 kV to 20 kV as the moisture increased from 5 ppm to 17 ppm.

On the other hand, it is shown that higher moisture content is required to cause significant reduction of AC BDV for VO as compared to MO. Martin & Wang (2006) showed that the AC BDV strength of natural ester decreased from 38 kV to 34 kV as the moisture increased from 31 ppm to 340 ppm. Other study showed that the AC BDV of natural ester decreased from 82 kV to 15.3 kV as the moisture increased from 128 ppm to 776 ppm (Primo et al., 2019). A previous study on rapeseed oil also showed that the increment of moisture from 40 ppm to 3,000 ppm caused the reduction of AC BDV from 61 kV to 8 kV (Mehmood et al., 2018). Another study had shown that 100 ppm of moisture could cause 11%, 37% and 17% reductions of AC BDVs for red palm oil, RBDPO and Palm Fatty Acid Ester (PFAE) (Suleiman et al., 2014). Murad et al. (2013) showed that the introduction of 700 ppm moisture in RBDPO, carotino oil and PFAE could caused reduction 67%, 49% and 82% of AC BDV, respectively. At the moment, there is a limited study that has been performed to examine the overall pattern of AC BDV of RBDPO versus moisture. The knowledge could be useful especially on identifying the AC BDV saturation level for RBDPO as compared to other types of VO.

In this study, the influence of moisture on the AC BDV of RBDPO was investigated. RBDPOs with different moisture contents were prepared by controlling the drying times of RBDPO in the oven. All RBDPOs were measured for moisture contents and AC BDVs and the parametric statistical techniques were used to analyze the AC withstand voltages.

MATERIALS AND METHODS

Samples Preparation

A membrane filter with a pore size of 0.2 μm was used to filter the RBDPO. In total, 3 times of filtration process was carried out to ensure the number of particles in the sample could be reduced as low as possible (Wang & Wang, 2008). The first sample of RBDPO was defined as "as-received". The RBDPO was dried in an air circulating oven at 85℃ for 6, 12, 18, 24, 30, 36, 42 and 48 hours individually to obtain different moisture contents. The volume for each of the samples was set to 500ml. After the drying process, all samples were further rested at ambient temperatures for at least 6 hours before the moisture and AC breakdown measurements were carried out.

Moisture Measurement

The moisture in RBDPO was measured by a Metrohm 831 Karl Fischer (KF) Coulometer as per ASTM D6304-16e1 (2016). For each of the moisture measurements, 1 ml of RBDPO was extracted and injected into titration vessel that contain CombiCoulomat fritless Karl Fischer reagent as seen in Figure 1. In total, 2 measurements were taken, and the average value was used for the analysis.

AC BDV Measurement

AC BDV of RBDPO was performed by an automatic BAUR DPA 75C breakdown tester based on ASTM D1816-12 (2019). The test was conducted at ambient temperatures. The gap distance between 2 VDE electrodes with a diameter of 36 mm was set to 1 mm. In total, 400 ml of RBDPO was used for the AC BDV test and it was carefully poured into the test cell in order to ensure there was no bubble formation as shown in Figure 2. The samples were rested for 15 minutes before the test was carried out. The test cell containing the RBDPO was placed in the test slot located within the BAUR DPA 75C breakdown tester. The voltage was automatically increased at 0.5 kV/s until the breakdown occurs between the 2 VDE electrodes and its corresponding breakdown voltage was recorded by the tester. Next, the RBDPO was automatically continuously stirred with a magnetic stirrer without any application of voltage for 5 minutes before the next breakdown test was carried out. The process was automatically repeated until 50 measurements were recorded for each of the samples.

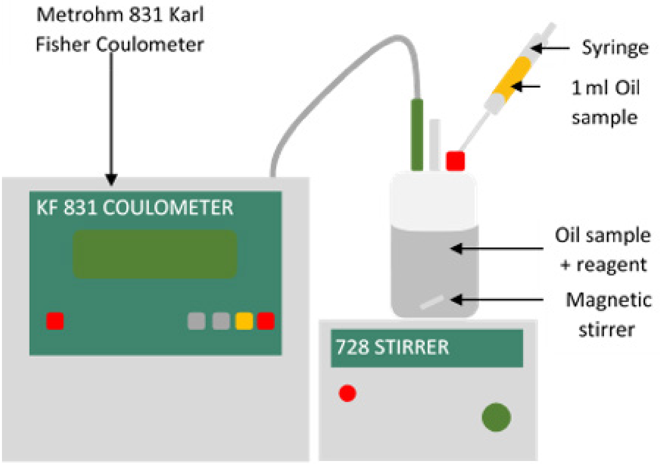


Figure 1. Moisture content test of the RBDPO

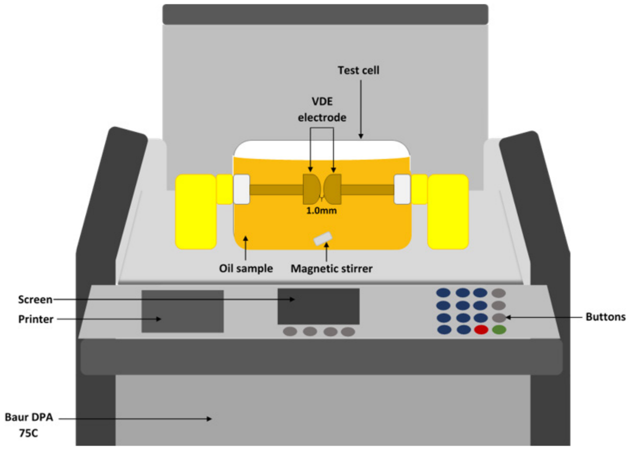
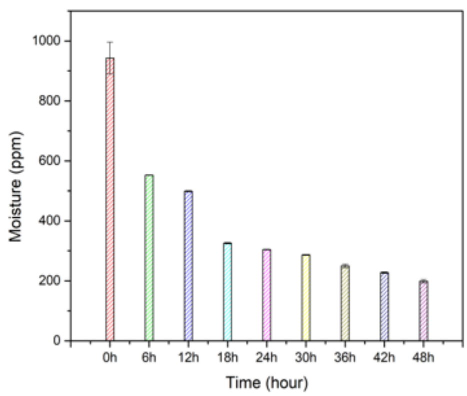


Figure 2. AC BDV test of the RBDPO

RESULTS AND DISCUSSION

Moisture Versus Drying Time

Moisture in RBDPO at different drying times can be seen in Figure 3a. It was observed that as the drying times increased, the moisture decreased exponentially. Apparent reduction of moisture up to 41% was found after 6 hours of drying. After 18 hours of drying, the reduction rate of moisture started to decrease. Between 18 hours and 48 hours of drying, the moisture decreased from 326 ppm to 199 ppm. The highest variation of the moisture content was observed for "as-received" samples as shown in Table 1. The variation decreased to a range between 1% and 3% with the increment of the drying time.



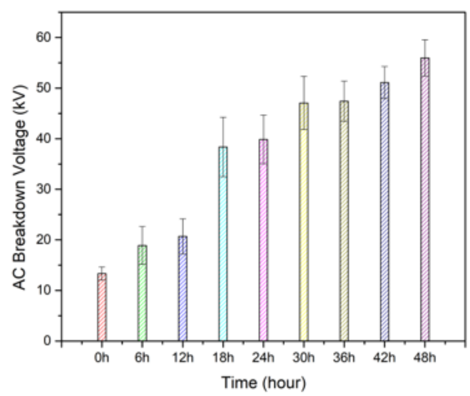


Figure 3. Relationship between (a) Moisture and drying time for RBDPO; (b) AC BDV and drying time for RBDPO

Table 1

Moisture content, standard deviation, and coefficient of variation according to drying time

Drying time (h)	Moisture content (ppm)	Standard deviation (ppm)	Coefficient of variation (%)
0	943	53.60	6
6	553	0.85	1
12	499	1.84	1
18	326	2.12	1
24	305	1.34	1
30	287	1.41	1
36	250	6.01	2
42	228	2.26	1
48	199	5.87	3

AC BDV Versus Drying Time

Linear increment of the AC BDV was found as the drying time increased as shown in Figure 3b. After 48 hours of drying, the AC BDV of RBDPO increases to 55.95 kV. The variation of AC BDVs is slightly different than moisture content as shown Table 2. The highest variation of AC BDV occured after 6 hours of drying. After 42 hours of drying, the variation of AC BDV stabilized whereby it was maintained at 6%.

Table 2
Mean AC BDV, standard deviation, and coefficient of variation according to drying time

Drying time (h)	Mean AC BDV (kV)	Standard deviation (kV)	Coefficient of variation (%)
0	13.34	1.31	10
6	18.88	3.75	20
12	20.68	3.50	17
18	38.37	5.87	15
24	39.86	4.82	12
30	47.06	5.27	11
36	47.41	3.97	8
42	51.09	3.16	6
48	55.95	3.58	6

AC BDV Versus Moisture

It is apparent that the moisture has an apparent effect on the AC BDV of RBDPO as shown in Figure 4. The AC BDV of RBDPO decreased exponentially with the increment of the moisture. The highest percentage of AC BDV decrement could be up to 76% as the moisture increased from 199 ppm to 943 ppm.

The variation of AC BDV at different instance intervals and moisture contents can be seen in Figure 4. It was observed that the variation of AC BDV for RBDPO at moisture of 943 ppm was quite low as shown in Figure 5a. On the other hand, high variations of AC BDVs for RBDPO were observed at moisture of 326 ppm, 305 ppm and 287 ppm as shown in Figure 5d, e, and f. The variations of AC BDVs for RBDPO were observed to be quite moderate at moisture of 553 ppm, 499 ppm, 250 ppm, 228 ppm and 199 ppm as seen in Figure 5b, c, g, h, and i, respectively.

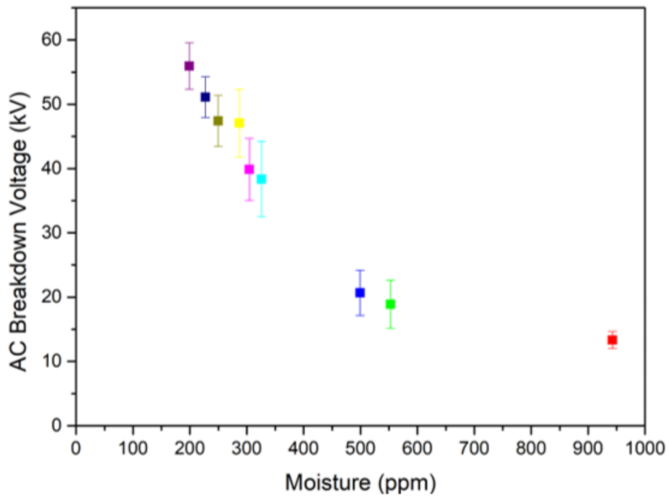


Figure 4. AC BDV versus moisture for RBDPO

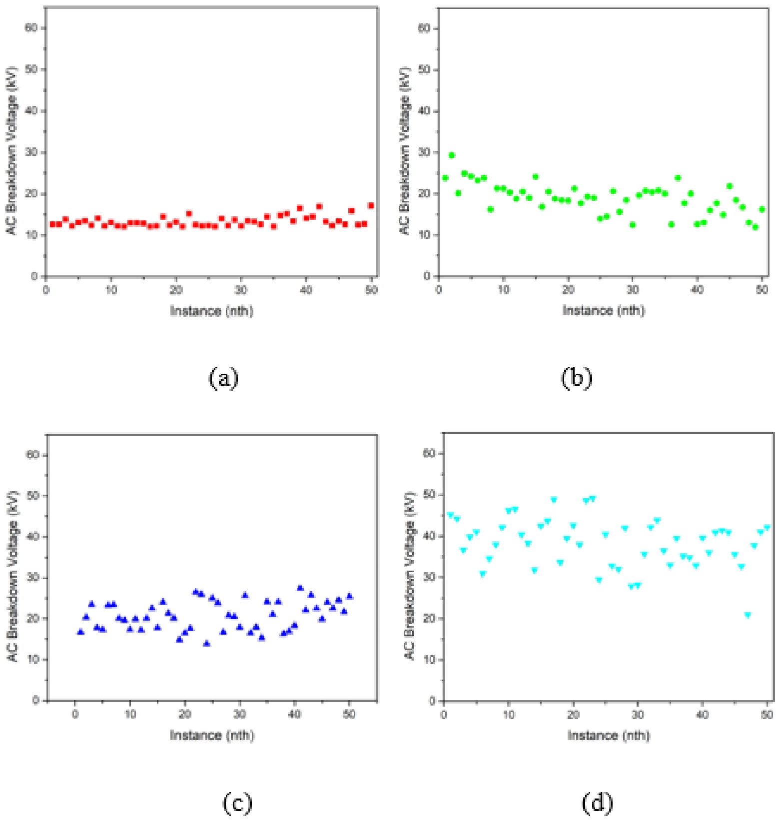
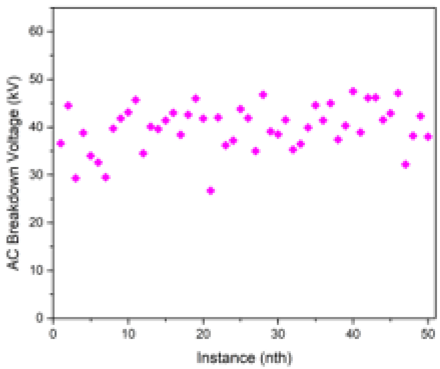
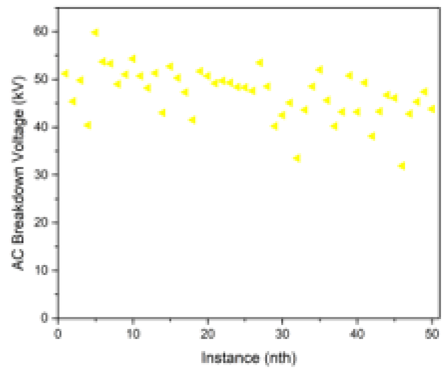


Figure 5. Distribution of AC BDV of RBDPO at moisture of (a) 943 ppm; (b) 533 ppm; (c) 499 ppm; (d) 326 ppm



(e)



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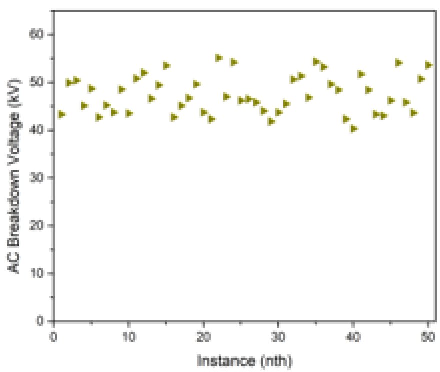
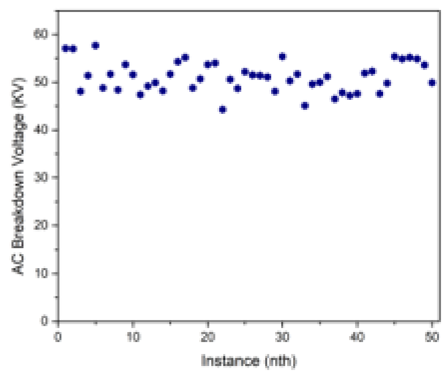
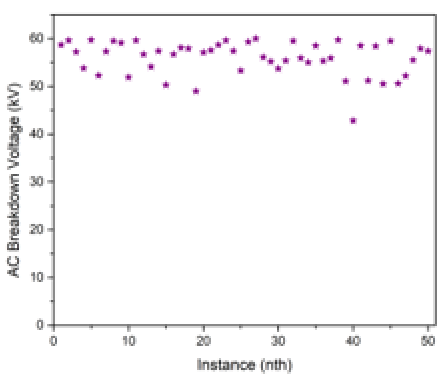


(g)



(h)



(i)

Figure 5. Distribution of AC BDV of RBDPO at moisture of (e) 305 ppm; (f) 287 ppm; (g) 250 ppm; (h) 228 ppm; (i) 199ppm

Statistical Analysis of AC BDV

Normal, lognormal and Weibull Cumulative Distribution Function (CDF) were the parametric techniques used to analyze the AC BDV data at different moisture contents. Equations 1 to 3 show the CDF models for normal, lognormal and Weibull distributions. For Equations 1 and 2, "x", "μ" and "σ" represent of data, mean and standard deviation respectively. On the other hand, the "x", "α" and "β" represents data, scale, and shape parameter for Equation 3.

$$F\ (x|\ \mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{\frac{-(t-\mu)^2}{2\sigma^2}}\ dt \qquad [1]$$

$$F\ (x|\mu,\sigma) = \left(\frac{1}{\sigma\sqrt{2\pi}}\right) \int_{0}^{x} \frac{1}{t} e^{\frac{-(\log t-\mu)^2}{2\sigma^2}}\ dt \qquad [2]$$

$$F\ (x|\ \alpha,\beta) = \int_{0}^{x} b a^{-b} t^{b-1} e^{-(\frac{t}{a})^b}\ dt \qquad [3]$$

Normal distribution or also well known as Gaussian distribution assumes that the data lie symmetrically close the mean of the data obtained (Martin & Wang, 2008). Kurtosis can be used to analyzed the extreme or less extreme values around the distribution based on Equation 4 (Martin & Wang, 2008). The symmetrical of the data is determined by analyzing the skewness as seen in Equation 5 (Martin & Wang, 2008). For Equations 4 and 5, the "n", "x_i" and "$\overline{X}$" represents of the sample size, individual value, and the mean of the sample, respectively.

$$g = \frac{n\sum_{i=1}^{n}(x_i-\bar{x})^4}{(\sum_{i=0}^{n}(x_i-\bar{x})^2)^2} \qquad [4]$$

$$s = \frac{\sqrt{n}\sum_{i=0}^{n}(X_i-\bar{X})^3}{(\sum_{i=0}^{n}(X_i-\bar{X})^2)^{3/2}} \qquad [5]$$

The skewness and kurtosis of the data for all samples can be seen in Table 3. Normally distributed data has the kurtosis of 3 and skewness of 0. If the kurtosis is less than 3, it means that the kurtosis is plytokurtic which indicates less extreme tail of the distribution. Kurtosis higher than 3 indicates leptokurtic distribution which mean extreme tail of the distribution. If the skewness is less than 0, the left tail of distribution is longer than right tail and vice versa if the value is higher than 0. Based on Table 3, it is apparent that the AC BDV data of RBDPO at different moisture contents had plytokurtic distribution whereby the tail was less extreme and concentrated mainly at the mean. Skewness analysis revealed that as the moisture decreased, the distribution tail shifted from right to left. Figure 6 shows the illustration of the AC BDV data distribution. It is shown the distribution of AC BDV data at moisture of 943 ppm has long right tail as shown in Figure 6a. The distributions of AC BDV data had no apparent extreme right or left tail as the moisture decreased from 553 ppm to 228 ppm as shown in Figure 6b, c, d, e, f, g, and h. As the moisture reached 199 ppm, the AC BDV data distribution started to exhibit long left tail as shown in Figure 6i.

Table 3
Kurtosis and skewness based on AC BDV data

Moisture content (ppm)	Mean AC BDV (kV)	Kurtosis for AC BDV data	Skewness for AC BDV data
943	13.34	1.31	1.36
553	18.88	0.11	0.11
499	20.68	-1.07	0.03
326	38.37	0.39	-0.44
305	39.86	0.24	-0.66
287	47.06	1.02	-0.61
250	47.41	-1.01	-0.30
228	51.09	-0.51	0.16
199	55.95	2.28	-1.34

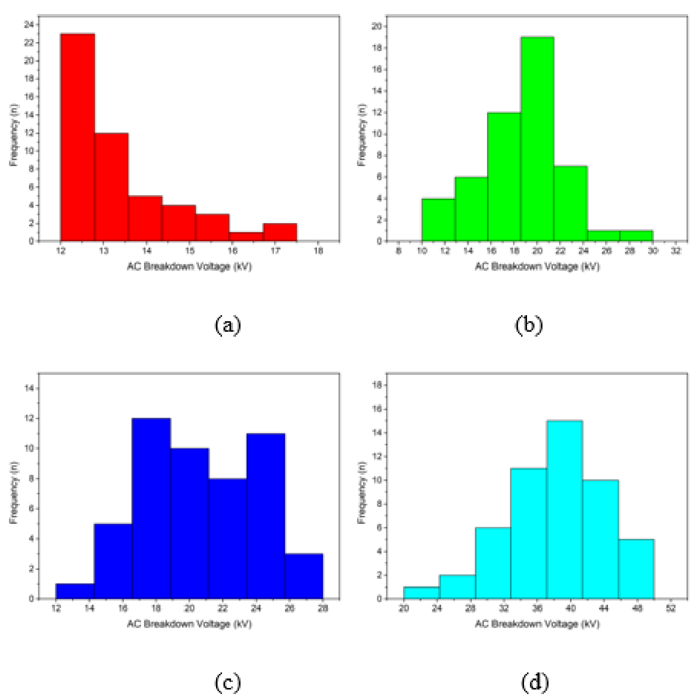


Figure 6. Histogram of frequency versus AC BDV of RBDPO at moisture of (a) 943 ppm; (b) 533 ppm; (c) 499 ppm; (d) 326 ppm

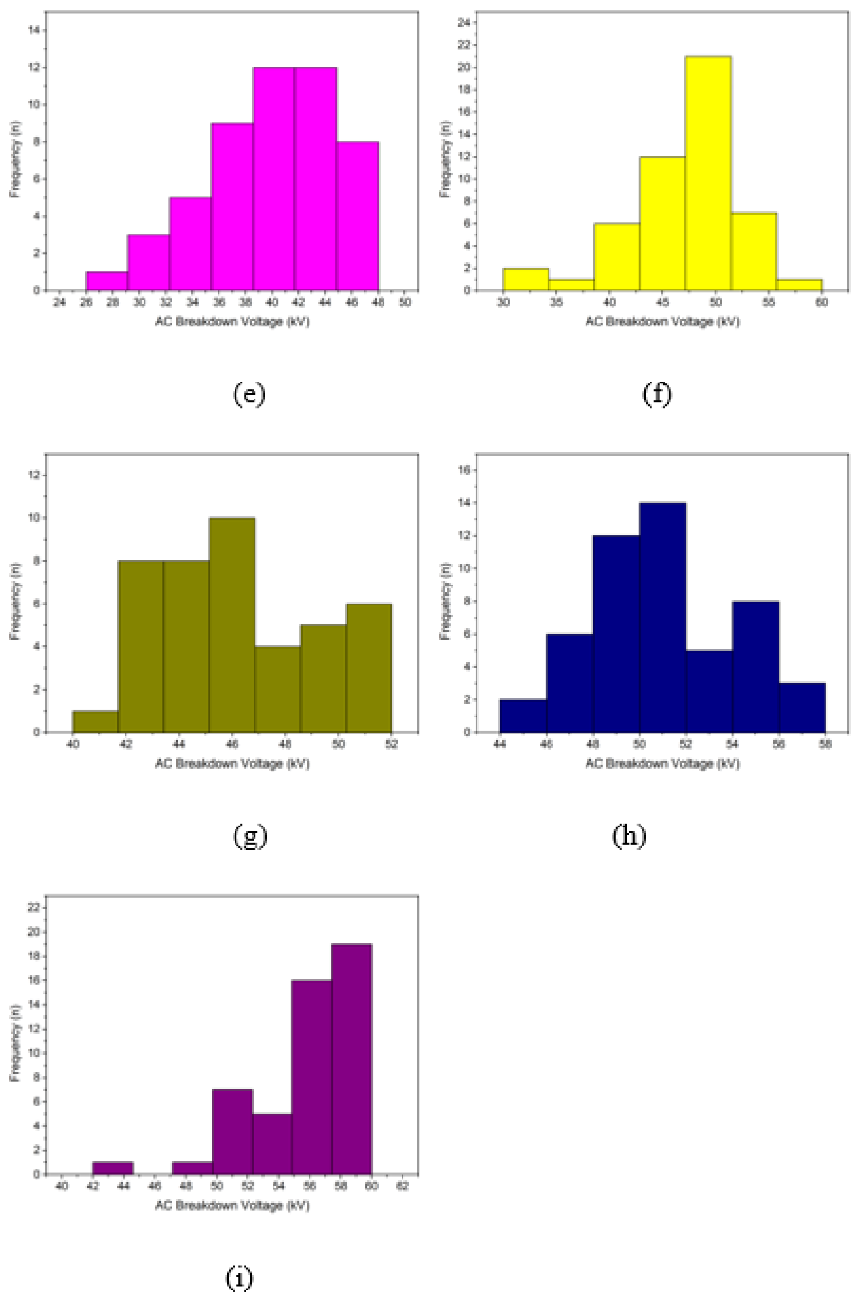


Figure 6. Histogram of frequency versus AC BDV of RBDPO at moisture of (e) 305 ppm; (f) 287 ppm; (g) 250 ppm; (h) 228 ppm; (i) 199ppm

The comparison among the fitted AC BDV data by normal, lognormal and Weibull distributions can be seen in Figures 7 to 9. Weibull distribution could represent most of the AC BDV data at moisture from 499 ppm to 199 ppm. The AC BDV data at moisture of 943 ppm and 553 ppm could not be represented by Weibull distribution whereby the data deviations occured at lower probability. Normal and lognormal distributions could represent the AC BDV at moisture of 943 ppm, 553 ppm and 499 ppm quite well as compared to Weibull distribution. However, as the moisture decreased, apparent data deviations occured at both lower and higher probabilities. Lognormal distribution performed better than normal distribution in term of representation the whole AC BDV data.

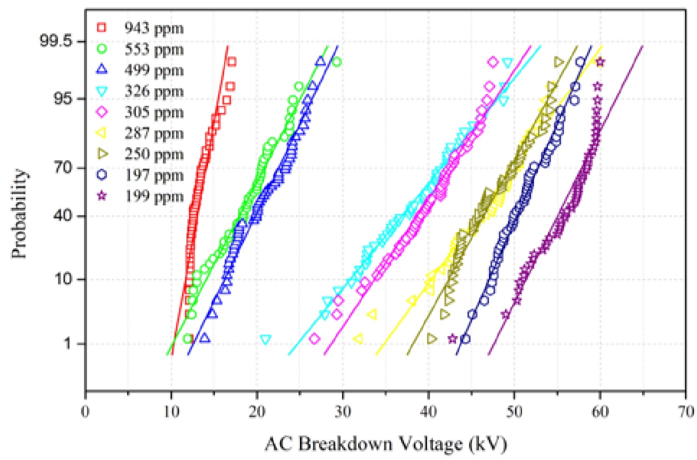


Figure 7. Normal probability plots of RBDPO

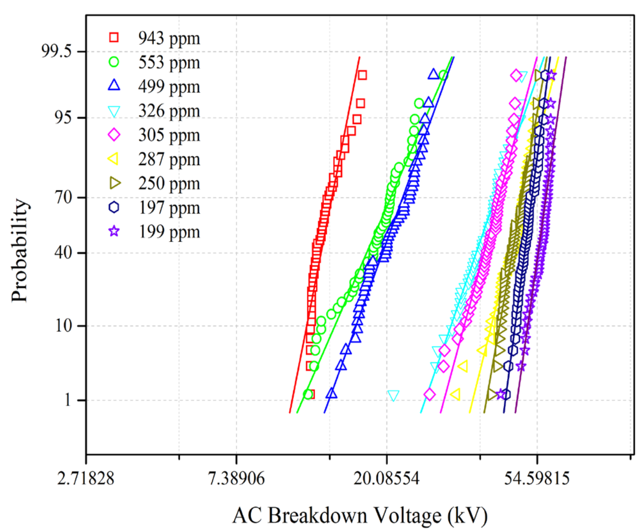


Figure 8. Lognormal probability plots of RBDPO

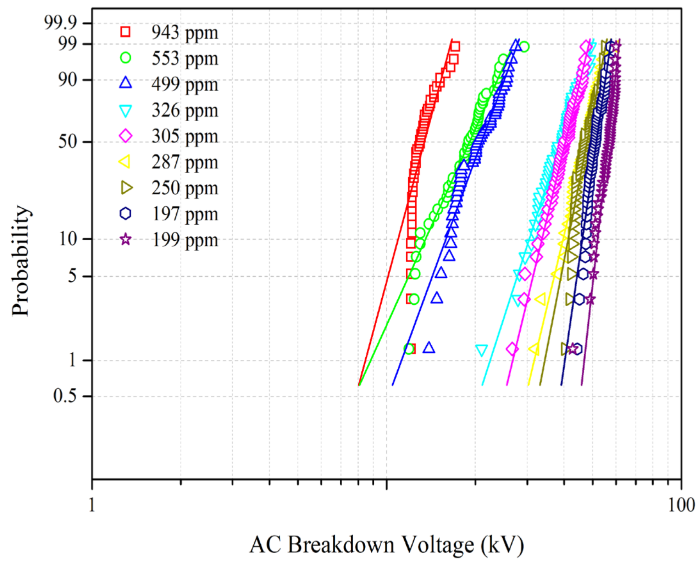


Figure 9. Weibull probability plots of RBDPO

The AC BDVs at 1%, 10%, 50% and 90% probabilities can be seen in Tables 4 to 7. It was found that the AC BDVs at 1%, 10% and 90% by lognormal distribution were slightly higher than other distributions. On the other hand, the AC BDV at 50% probability by Weibull distribution was slightly higher than other distributions. At 1%, 10% and 50% probabilities, the AC BDVs obtained by the Weibull distribution had the highest increments as moisture decreased from 943 ppm to 199 ppm with percentages of 453%, 375% and 321%. At 1% and 10% probabilities, the AC BDVs obtained by the normal distribution had the second highest of increment of 362% and followed by the lognormal distribution of 346% and 334%. At 50% probability, the AC BDV increment for lognormal distribution was slightly higher than normal distribution of 320%. At 90% probability, the AC BDV by lognormal distribution had the highest increment of 307%. The second highest of increment at 90% probability was normal distribution followed by Weibull distribution of 303% and 289% respectively.

Table 4

AC BDV at 1% probability according to parametric methods

Drying times (h)	Moisture content (ppm)	1% probability (kV)		
		Normal	Lognormal	Weibull
0	943	10.30	10.70	8.47
6	553	10.16	11.46	8.82

Table 4 (Continued)

Drying times (h)	Moisture content (ppm)	1% probability (kV)		
		Normal	Lognormal	Weibull
12	499	12.56	13.66	11.21
18	326	25.05	25.88	22.45
24	305	28.65	29.36	26.77
30	287	34.81	35.52	31.68
36	250	38.18	38.94	34.38
42	228	43.75	44.18	40.25
48	199	47.62	47.75	46.82

Table 5

AC BDV at 10% probabilities according to parametric methods

Drying times (h)	Moisture content (ppm)	10% probability (kV)		
		Normal	Lognormal	Weibull
0	943	11.67	11.79	10.93
6	553	14.07	14.21	13.53
12	499	16.21	16.35	15.87
18	326	31.18	30.72	30.46
24	305	33.69	33.56	33.65
30	287	40.31	40.18	39.71
36	250	42.32	42.47	41.31
42	228	47.05	47.12	46.13
48	199	51.36	51.22	51.97

Table 6

AC BDV at 50% probability according to parametric methods

Drying times (h)	Moisture content (ppm)	50% probability (kV)		
		Normal	Lognormal	Weibull
0	943	13.34	13.28	13.42
6	553	18.88	18.45	19.08
12	499	20.68	20.38	20.98
18	326	38.70	37.89	38.91

Table 6 (Continued)

Drying times (h)	Moisture content (ppm)	50% probability (kV)		
		Normal	Lognormal	Weibull
24	305	39.86	39.55	40.42
30	287	47.06	46.75	47.59
36	250	47.41	47.24	47.87
42	228	51.09	50.99	51.47
48	199	55.95	55.83	56.51

Table 7

AC BDV of 90% probability based on parametric method

Samples	Moisture content (ppm)	90% probability (kV)		
		Normal	Lognormal	Weibull
0	943	15.01	14.96	15.29
6	553	23.68	24.08	23.74
12	499	25.15	25.41	25.04
18	326	46.22	46.75	45.47
24	305	46.04	46.61	45.43
30	287	53.81	54.39	53.41
36	250	52.49	52.56	52.58
42	228	55.13	55.19	55.18
48	199	60.54	60.86	59.60

CONCLUSION

According to the current study, it is found that the drying process does help with the improvement of the AC BDV of RBDPO through reduction of moisture. The AC BDV of RBDPO decreases exponentially with the increment of the moisture. The AC BDV data of RBDPO has a plytokurtic distribution whereby the distribution tail shift from right to left as the moisture increases. Weibull distribution can represent most of the AC BDV data of RBDPO at different moisture contents quite well as compared to the normal and lognormal distributions.

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REFERENCES

Aditama, S. (2005). Dielectric properties of palm oils as liquid insulating materials: Effects of fat content. In *Proceedings of 2005 International Symposium on Electrical Insulating Materials, 2005. (ISEIM 2005)* (Vol. 1, pp. 91-94). Tokyo, Japan: Yasuo Muraoka. doi: 10.1109/ISEIM.2005.193334

ASTM D1816-12. (2019). *Standard test method for dielectric breakdown voltage of insulating liquids using VDE electrodes.* West Conshohocken, USA: ASTM International

ASTM D6304-16e1. (2016). *Standard test method for determination of water in petroleum products, lubricating oils, and additives by Coulometric Karl Fischer Titration*. West Conshohocken, USA: ASTM International

Azis, N., Jasni, J., Kadir, M. Z. A., & Mohtar, M. N. (2014). Suitability of palm based oil as dielectric insulating fluid in transformers. *Journal of Electrical Engineering and Technology*, *9*(2), 662-669. doi: 10.5370/jeet.2014.9.2.662

Heathcore, M. K. (2007). *The J and P transformer book*. Oxford, United Kingdom: Elservier.

Kiasatina, Kamarol, M., Zulhilmey, M., & Arief, Y. A. (2011, June 21-22). Breakdown characteristics of RBDPO and soybean oil mixture for transformer application. In *Proceedings of the International Conference on Electrical, Control and Computer Engineering 2011 (InECCE)* (pp. 219-222). Pahang, Malaysia. doi: 10.1109/INECCE.2011.5953879

Martin, D., & Wang, Z. D. (2006, October 15-18). A comparative study of the impact of moisture on the dielectric capability of esters for large power transformers. In *Proceedings of 2006 Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (pp. 409 - 412). Kansas City, MO, USA. doi: 10.1109/CEIDP.2006.311956.

Martin, D., & Wang, Z. D. (2008). Statistical analysis of the AC breakdown voltages of ester based transformer oils. *IEEE Transactions on Dielectrics and Electrical Insulation, 15*(4), 1044-1050. doi: 10.1109/TDEI.2008.4591226

Martins, M. A. G. (2010). Vegetable oils, an alternative to mineral oil for power transformers-experimental study of paper aging in vegetable oil versus mineral oil. *IEEE Electrical Insulation Magazine, 8*(3), 7-13. doi: 10.1109/MEI.2010.5599974

Mehmood, M. A., Li, J., Huan, Z., Wang, F., Li, X., Bhutta, M. S., & Li, X. (2018, September 10-13). Effects of suspended moisture particles on AC breakdown voltage and electric field distribution of vegetable insulation oil. In *Proceedings of 2018 IEEE International Conference on High Voltage Engineering and Application (ICHVE)* (pp. 1-4). Athens, Greece. doi: 10.1109/ICHVE.2018.8641957

Mohamad, N. A., Azis, N., Jasni, J., Kadir, M. Z. A., Yunus, R., Ishak, M. T, & Yaakub, Z. (2015). A study on the dielectric properties of RBDPO olein under low temperature thermal ageing. *Applied Mechanics and Materials, 793*, 14-18. doi: 10.4028/www.scientific.net/AMM.793.14

Mohamad, N. A., Azis, N., Jasni, J., Kadir, M. Z. A., Yunus, R., Ishak, M. T., & Yaakub, Z. (2014, December 1-3). A study on the dielectric properties of palm oil and coconut oil. In *Proceedings of the 2014 IEEE International Conference on Power and Energy (PECon)* (pp. 109-112). Kuching, Malaysia. doi: 10.1109/PECON.2014.7062423

Murad, N. S., Muhamad, N. A., Suleiman A. A., & Jamail, N. A. M. (2013, October 20-23). A study on palm oil-based oil moisture absorption level and voltage breakdown. In *Proceedings of 2013 Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (pp. 925-928). Shenzhen, China. doi: 10.1109/CEIDP.2013.6748188

Oommen, T. V. (2002). Vegetable oils for liquid-filled transformers. *IEEE Electrical Insulation Magazine, 18*(1), 6-11. doi: 10.1109/57.981322

Primo V. A., García, B., Pérez, D., & Burgos, J. C. (2019, June 23-27). Analysing the impact of moisture on the AC breakdown voltage on natural ester based nanodielectric fluids. In *Proceedings of 2019 IEEE 20th International Conference on Dielectric Liquids (ICDL)* (pp. 1-4). Roma, Italy. doi: 10.1109/ICDL.2019.8796675

Rafiq, M., Lv, Y. Z., Zhou, Y., Ma, K. B., Wang, W., Li, C. R., & Wang, Q. (2015). Use of vegetable oils as transformer oils - A review. *Renewable and Sustainable Energy Reviews, 52*, 308-324. doi: https://doi.org/10.1016/j.rser.2015.07.032

Suleiman, A. A., Muhamad, N. A., Bashir, N., Murad, N. S., Arief, Y. Z., & Phung, B. T. (2014). Effect of moisture on breakdown voltage and structure of palm based insulation oils. *IEEE Transactions on Dielectrics and Electrical Insulation, 21*(5), 2119-2126. doi: 10.1109/TDEI.2014.004431

Suleiman, A., & Muhamad, N. A. (2011). A case for the establishment of Malaysian standard for biodegradable insulation oil in Malaysia transformers. *International Review on Modelling and Simulations, 4*(6), 2756-2763.

Suwarno, S., & Prakoso, M. (2015). Effects of water content on dielectric properties of mineral transformer oil. *International Journal of Electrical and Computer Engineering, 9*(10), 1142-1146. doi: 10.5281/zenodo.1109353

Suwarno, Sitinjak, F., Suhariadi, I., & Imsak, L. (2003, June 1-5). Study on the characteristics of palm oil and it's derivatives as liquid insulating materials. In *Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials* (Vol. 2, pp. 495-498). Nagoya, Japan. doi: 10.1109/ICPADM.2003.1218461

Takaaki, K., Hiroyuki, I., Yoshiyuki, H., Junichi, Y., Tomoyuki, H., Akina, Y., … & Yasunori, H. (2008, June 30 - July 3). Analyses of electro-chemical characteristics of palm fatty acid esters as insulating oil. In *Proceedings of 2008 IEEE International Conference on Dielectric Liquids* (pp. 1-4). Futuroscope-Chasseneuil, France. doi: 10.1109/ICDL.2008.4622456

Tenbohlen, S., & Koch, M. (2010). Aging performance and moisture solubility of vegetable oils for power transformers. *IEEE Transactions on Power Delivery, 25*(2), 825-830. doi: 10.1109/TPWRD.2009.2034747

Wang, X., & Wang, Z. D. (2008, October 26-29). Particle effect on breakdown voltage of mineral and ester based transformer oils. In *Proceedings of 2008 Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (pp. 598-602). Quebec, Canada. doi: 10.1109/CEIDP.2008.4772859