

Influence of Kraft Paper on the Ageing of Palm Oil, Corn Oil and Rice Bran Oil (Pengaruh Kertas pada Penuaan Minyak Kelapa Sawit, Minyak Jagung dan Minyak Dedak Padi)

M. M. Ariffin^a, M. T. Ishak^{a,*}, M. H. A. Hamid^a, F. R. Hashim^a, M. F. Md Din^a & R. Abd Rahman^b

^aDepartment of Electrical and Electronic Engineering, Faculty of Engineering, National Defence University of Malaysia, Sg. Besi Camp, Kuala Lumpur, Malaysia

^bFaculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

*Corresponding author: mtaufiq@upnm.edu.my

Received 25 March 2021, Received in revised form 13 April 2021
Accepted 31 September 2021, Available online 30 October 2018

ABSTRACT

This paper presents a sealed ageing study of palm oil, corn oil, and rice bran oil with and without the presence of insulation paper. The oils were aged at four different durations which are at 2 days, 30 days, 90 days, and 180 days at a constant temperature of 90°C. The properties of vegetable oils as well as insulation paper under ageing were then analysed through AC breakdown voltage, dielectric losses, relative permittivity, resistivity, moisture, and acidity of the oils. It is found that the AC breakdown voltage of oils with the presence of insulation paper is lower than the oils without the insulation paper. The AC breakdown of oils with and without insulation paper increase with the ageing time which reflect the amount of moisture in oil. For dielectric loss, the value is increased with time and dielectric loss with paper shows lower value than without paper. RBO shows higher dielectric losses for both conditions. In term relative permittivity, it can be concluded that the relative permittivity increases when the time ageing increase. It is seen that relative permittivity of palm oil is the highest change in duration of time ageing from 1.8 to 2.0 for both conditions. Throughout the ageing time, the acidities of all the oil samples remain at low level for ageing without paper. However, with the presence of paper, the number of acidities for all oil samples increased with the time. With the presence of Kraft paper, the viscosity will decrease over time duration. But, without the presence of Kraft paper, the viscosities were almost stable for all samples.

Keywords: Ageing; temperature; kraft paper; vegetable oils

ABSTRAK

Makalah ini membentangkan kajian penuaan minyak sawit, minyak jagung, dan minyak dedak beras dengan dan tanpa adanya kertas penebat. Minyak itu telah melalui proses penuaan pada empat jangka masa berbeza iaitu pada 2 hari, 30 hari, 90 hari, dan 180 hari pada suhu tetap 90°C. Sifat minyak sayuran dan kertas penebat di bawah penuaan kemudian dianalisis melalui voltan kerosakan AC, kehilangan dielektrik, kebolehtelapan relatif, ketahanan, kelembapan, dan keasidan minyak. Didapati bahawa voltan kerosakan minyak dengan kehadiran kertas penebat lebih rendah daripada minyak tanpa kertas penebat. Pemecahan minyak AC dengan dan tanpa kertas penebat meningkat dengan masa penuaan yang mencerminkan jumlah kelembapan minyak. Untuk kehilangan dielektrik, nilainya meningkat dengan masa dan kehilangan dielektrik dengan kertas menunjukkan nilai yang lebih rendah daripada tanpa kertas. RBO menunjukkan kerugian dielektrik yang lebih tinggi untuk kedua-dua keadaan. Dalam jangka masa kebolehtelapan relatif, dapat disimpulkan bahawa permissiviti relatif meningkat apabila penuaan waktu meningkat. Ia dilihat bahawa kebolehtelapan relatif minyak sawit adalah perubahan tertinggi dalam jangka masa penuaan dari 1.8 hingga 2.0 untuk kedua-dua keadaan. Sepanjang masa penuaan, keasidan semua sampel minyak tetap berada pada tahap rendah untuk penuaan tanpa kertas. Namun, dengan adanya kertas, jumlah keasidan untuk semua sampel minyak meningkat seiring berjalannya waktu. Dengan adanya kertas Kraft, kelikatannya akan berkurang sepanjang jangka masa. Tetapi, tanpa kehadiran kertas Kraft, kelikatan hampir stabil untuk semua sampel.

Kata kunci: Penuaan; suhu; kertas Kraft; minyak sayur

INTRODUCTION

In recent years, the study of vegetable oils as dielectrics and coolant in power transformer has been intensively done (Abdelmalik et al. 2013). The reasons why vegetable oils have been chosen as alternative to mineral oil because of its high flash and fire point, higher biodegradable, and non-toxicity compared to mineral oil (Carcedo et al. 2016). However, vegetable oils have higher viscosity and easily oxidized than mineral oil in normal condition. Table 1 shows the relative comparison of mineral oil (MO) and vegetable oil (VO) (Ariffin et al. 2017).

Since the vegetable oils showed promising results as alternative to mineral oil (MO), further study needs to be done especially in knowing the behavior of the oil-paper insulation system and its ageing performance (Carcedo et al. 2015).

Ageing of insulation is a combination of temperature, moisture, and oxygen and causing the deterioration of insulation (Costanzo 1999). Ageing of insulating oils uses an oven to facilitate the heat transfer in a container. Different researcher reported that coloration, oxidation, increased acid number, water content, and increased dielectric losses are general indicator of oil ageing (Ariffin et al. 2017).

In this paper, we discuss the electrical and psychochemical properties of vegetables insulating oils. The accelerated ageing of the oils was performed in two methods. The first method is oil presence with Kraft paper and the second method is oil without the presence of Kraft paper. The ageing of both methods subjected to ageing in 2, 30, 90, and 180 days with constant temperature of 90°C in an oven.

TABLE 1. Comparison of high fire point and less flammable liquid filled transformer type, and their attributes for mineral oil and natural ester

Attributes	Mineral Oil	Vegetable Oil
Fire Resistance	Poor	Excellent
Environmental impact	Moderate	Excellent
Life expectancy at maximum temperature rating	Good	Good
Efficiency	High	High
Sound level	Low	Low
Operating temperature	Low	Low
Contamination resistance	Excellent	Excellent
Overload capacity	Good	Excellent
First cost	Low	Moderate
Energy costs	Low	Low
Recycle/Disposal costs	Low	Low

Source: Ariffin et al. (2017)

MATERIAL AND METHOD

Laboratory tests consisting of thermally accelerated ageing with the presence of Kraft paper and without the presence

of Kraft paper were carried out. The properties of oil used in this study are shown in Table 2 with follow the ASTM and IEC standard.

TABLE 2. Properties of oils used in this study

Properties	Unit	Standard
AC Breakdown Voltage (2.5 mm)	kV	IEC 60156
Relative Permittivity		IEC 60247
Resistivity	GΩ.cm	IEC 60247
Dielectric Losses		IEC 60247
Moisture Content (Oil)	ppm	ASTM D1533
Acidity	Mg.KOH/g	ASTM D974
Viscosity	Pa.s	ASTM D445

The vegetable oils tested in this experiment were palm oil, corn oil and rice bran oil which

is obtained from cooking oil in the market. The samples were divided into two methods where the first method is oil with Kraft paper and the second method is oil only. Each sample was filtered in 1 liter bottles. The sample preparations are shown in Figure 1.



(a)



(b)

FIGURE 1. Sample preparation of oils (a) With the presence of Kraft paper and (b) Without the presence of Kraft paper

Before all samples were divided into two methods, the sample was filtered with membrane filter which have the pore size $0.2 \mu\text{m}$. Then, all samples were dried at 85°C in the vacuum oven for two days (48 hours) for moisture stripping. Next, the preparation of Kraft paper which has $0.07 \times 20 \text{ mm}$ measurement. Firstly, 70 g of Kraft paper was cut, rolled and tied, and placed in the oven for two days (48 hours) under 105°C . The oils and paper were then put together in a sealed bottle and put in an oven for further 24 hours at ambient temperature. The prepared

sample was oven aged at 90°C for 2, 30, 90, and 180 days. These temperatures allowed us to perform a test without the risk of side effect due to pyrolysis or carbonization (Abdelmalik et al. 2013).

Depending on constant 90°C temperature and different period of ageing, all samples were tested in electrical properties which are AC breakdown voltage, relative permittivity, resistivity, and dielectric losses. Then, for all samples, the parameters of acidity, moisture content in oil, and viscosity were studied. The measured data was recorded and plotted in OriginLab software.

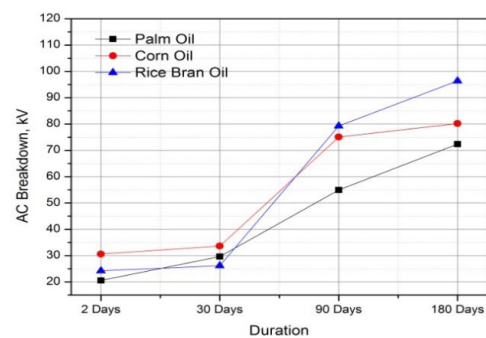
RESULT AND DISCUSSION

The ageing tests were done at constant temperature of 90°C for 2, 30, 90 and 180 days using palm oil (PO), corn oil (CO), and rice bran oil (RBO).

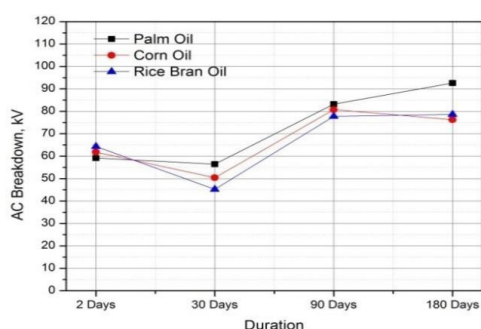
EFFECT OF AC BREAKDOWN VOLTAGE AND MOISTURE WITH AGEING

Figure 2 shows the influence of ageing in AC breakdown voltage for all period on the oil with the presence of Kraft paper and without the presence of Kraft paper.

The AC breakdown voltage is the most important test for liquid insulating oils. The AC breakdown voltage is an important test to study the ability of fluid to withstand dielectric stresses (Costanzo et al. 1999). The quality of oils is the main criteria for sensitivity of AC breakdown. This is because insulating oil can be the influence of presence of different contaminants such as moisture and water droplet, dirt, gases, and other particles (Costanzo et al. 1999). The breakdown voltage was applied across the electrodes of the test cell with an increasing rate of 2 kV/s . A total of 100 breakdown voltages were recorded for each type of samples (Costanzo et al 1999; Choi & Huh 2013).



(a)



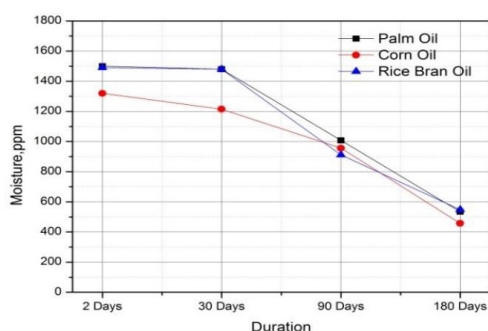
(b)

FIGURE 2. Influence of Kraft paper in oil for AC breakdown voltage; (a) with the presence of Kraft paper, (b) without the presence of Kraft paper

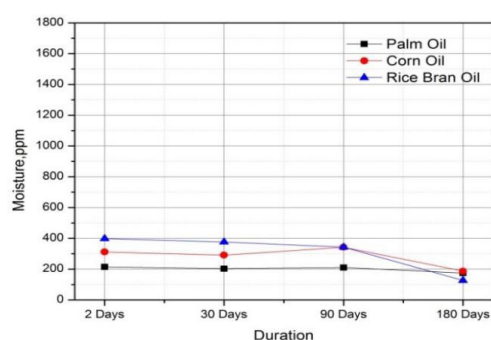
Figure 2(a) and 2(b) show the AC breakdown in oil with the presence of Kraft paper and without the presence of Kraft paper for all period of ageing with constant temperature of 90°C. From the results, it shows that the AC breakdown for both methods increased as the ageing time increase. But, the results for oils with the presence of paper were higher with a value of 100 kV compared to oils without Kraft paper at 95 kV.

From Figure 2(a), corn oil has the highest AC breakdown when aged 2 days, followed by rice bran oil and palm oil. The AC breakdowns rapidly increase after they were aged at 90 days for all samples.

As we know, the breakdown of insulating oils are highly dependent on foreign particles, moisture, and spaces charge (Martin et al. 2006). The higher the moisture in oil, the lower the AC breakdown voltage will be. In this case, the moisture for both oil conditions decreases when the ageing time increases. This finding agrees with the results of breakdown voltage in this study where the breakdown voltage increases when the ageing time increase. The moisture were higher in samples with the presence of Kraft paper because of the absorption of water in vegetable oils is higher (Garcis et al. 2017). Figure 3(a) shows a graph of moisture in oil with the presence of Kraft paper and Figure 3(b) shows the moisture in oil without the presence of Kraft paper.



(a)



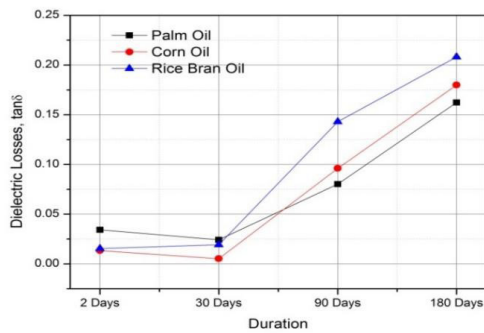
(b)

FIGURE 3. Influence of moisture in oil (a) Moisture in oil with the presence of Kraft paper (b) Moisture in oil without the presence of Kraft paper

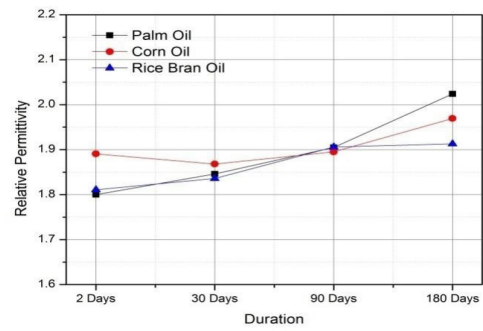
EFFECT OF DIELECTRIC LOSSES WITH AGEING

The dielectric losses of all samples were measured using ADTR-2K PLUS oil tester. The temperature was set to 90 °C and the volume of the oil in the test container is around 45 ml and the frequency was set to 60 Hz (Choi & Huh 2013). Figure 4 shows the influence of Kraft paper on dielectric losses.

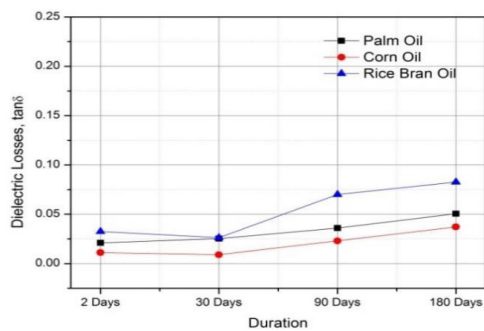
Dielectric losses represent the application of an AC electric field and its proportional to electric conductivity (Haramija et al. 2014). A low dielectric loss indicates low AC electric field. Figure 4 shows the influence of Kraft paper on dielectric losses. Figure 4(a) shows the dielectric losses of oil with the presence of Kraft paper. After 2 days of ageing, palm oil possessed the highest dielectric loss, followed by rice bran oil and corn oil. However, when ageing time reached 30 days, the dielectric losses of vegetable oils rapidly increased until they reach 180 days ageing. Figure 4(b) shows the dielectric losses of oil without the presence of Kraft paper. The rice bran oil possessed the highest value after 2 days of ageing, followed by palm oil and corn oil. When they reach 180 days ageing, the rice bran oil still had the highest value of dielectric loss followed by palm oil and corn oil. It shows that the electric field of vegetable oils will increase when the time of ageing increase. Both methods show that the rice bran oil had the highest value for dielectric losses when it reached 90 days to 180 days ageing which means it indicates high value of presence of moisture (Liao et al. 2010) shown in Figure 3. Also, we can say that the increased time of ageing will make the oil become degraded and increase the acids, so the dielectric losses will increase too.



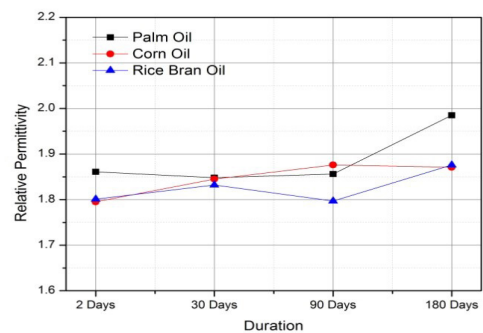
(a)



(a)



(b)



(b)

FIGURE 4. Influence of Kraft paper on dielectric losses (a) Dielectric losses of oil with the presence of Kraft paper (b) Dielectric losses of oil without the presence of Kraft paper

FIGURE 5. Influence of Kraft paper on relative permittivity (a) Relative permittivity with the presence of Kraft paper (b) Relative permittivity without the presence of Kraft paper

EFFECT OF RELATIVE PERMITTIVITY WITH AGEING

Relative permittivity parameter was the measurement of capacitance of test cell. The ratio between capacitance of oil filled test cell to the capacitance of empty cell represents the relative permittivity of oil (Haramija et al. 2014). The experiment was measured as per dielectric loss.

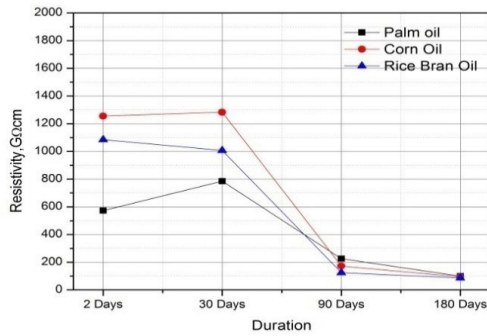
Figure 5 shows the influence of Kraft paper on relative permittivity with the presence of Kraft paper and without Kraft paper for vegetable oils at 90 °C with different time of ageing. Figure 5 (a) shows that there is a slight increase in the relative permittivity as time of ageing increased. At 2 days of ageing, it shows that the corn oil possessed the highest value of relative permittivity 1.89 at 90°C, followed by rice bran oil and palm oil. But when the sample of oils were aged until 180 days, the palm oil obtained the highest value of relative permittivity followed by corn oil and rice bran oil.

Figure 5(b) shows the relative permittivity without the presence of Kraft paper. From the graph, it shows that palm oil possessed the highest and stable value of relative permittivity up to 90 days of ageing, but rapidly increased when it reached 180 days of ageing. The relative permittivities of rice bran oil increased from 2 days until 30 days of ageing and then slightly decreased when it reached 90 days of ageing but increased again as it reaches 180 days of ageing. For corn oil, the relative permittivity increased until 90 days of ageing and decreased when it reached 180 days of ageing.

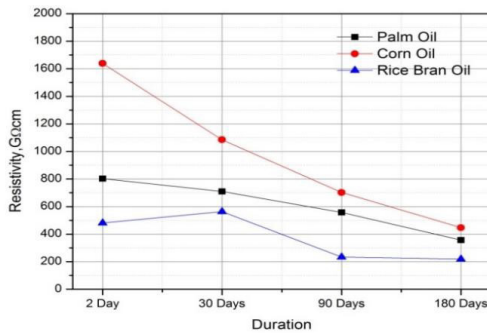
From both results, it can be concluded that the relative permittivity increases when the time of ageing increased. It is seen that relative permittivity changed in duration of time of ageing from 1.8 to 2.0 for both results. The higher relative permittivity value will give more uniformed electric field especially for oil-paper interface. This will reduce the stress of the oil (Haramija et al. 2014).

EFFECT OF OIL RESISTIVITY WITH AGEING

Figure 6(a) shows resistivity with the presence of Kraft paper. It is seen that resistivity of the oil generally is in a decreasing trend with increasing duration of time. From previous research, it concludes that resistivity depends on frequency, dissipation factor, and relative permittivity (Martin et al. 2006).



(a)



(b)

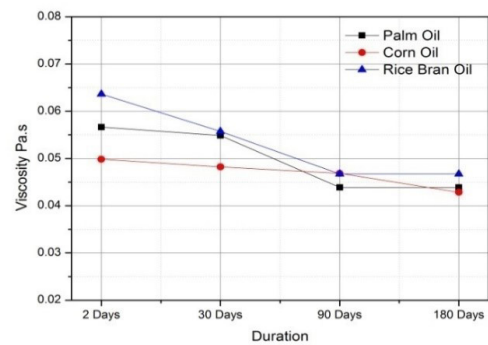
FIGURE 6. Influence of Kraft paper on resistivity, GΩ.cm (a) Resistivity, GΩ.cm with the presence of Kraft paper (b) Resistivity, GΩ.cm without the presence of Kraft paper

From figure 6(b), it shows the resistivity without the presence of Kraft paper. It also shows the decreasing trend with increasing duration in time. It concludes that the presence of Kraft paper or without Kraft paper, the resistivity will decrease over time duration. The corn oil from Figure 6(a) and 6(b) shows higher resistivity in both conditions.

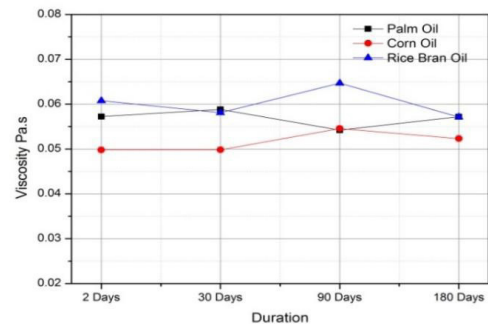
EFFECT OF OIL VISCOSITY WITH AGEING

Viscosity is an important parameter for transformer insulating liquid. Viscosity is defined as the ability of oil to flow under specified conditions. The higher viscosity of oil will affect the heat transfer properties of oil and, consequently, the temperature rises in the transformer.

Figure 7(a) and 7(b) shows the influence of Kraft paper on viscosity with the presence of Kraft paper and without Kraft paper. The viscosities of corn oil are the lowest value with or without Kraft paper. Obviously, good oil should have low viscosity so that it offers less resistance to the conventional flow of oil thereby not affecting cooling of transformer. With the presence of Kraft paper, the viscosity will decrease over time duration as shown in Figure 7(a). When the time of ageing increase, the Kraft paper absorbs more water from the oil and causes the oil to become more viscose to the oil (Mcshane et al. 2001). But, without the presence of Kraft paper, the viscosities were almost stable for all samples.



(a)



(b)

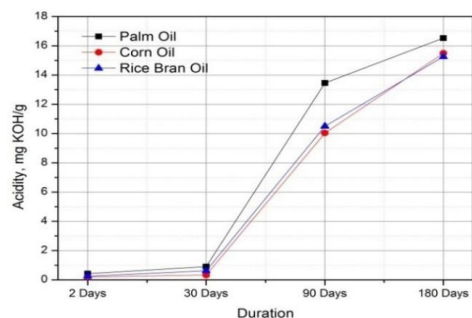
FIGURE 7. Influence of Kraft paper on viscosity, Pa.s (a) Viscosity, Pa.s with the presence of Kraft paper (b) Viscosity, Pa.s without the presence of Kraft paper

EFFECT OF ACIDITY WITH AGEING

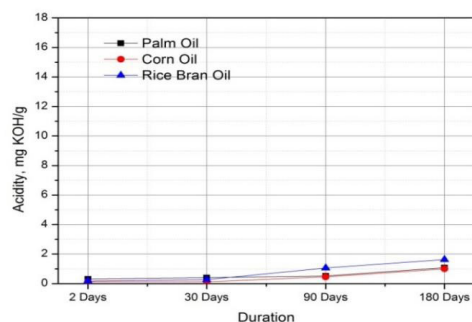
Acidity of the oil is a measure of acidic contaminants in the oil (Abdelmalik. 2013). Acids and oxidation with water and solid contaminants will affect the dielectric properties of the oil. Figure 8(a) shows the acidity with the presence of Kraft paper. It shows that the rate of acidity for all samples rapidly increase after having 30 days of ageing time. It is because of the acids itself having an impact on the degradation of cellulosic materials from Kraft paper and may also result from the metal parts of the transformer

itself. If the acidity is high, the transformer will accelerate ageing time because acidity is a good indicator of the rate of ageing. The vegetable oil significantly increases the thermal stability of the Kraft paper (Meshane et al. 2001).

Figure 8(b) shows the acidity without the presence of Kraft paper. The rate of acids increased slowly after 30 days of ageing. Without the Kraft paper, there are no degradation of cellulosic materials and the acidity becomes lower even though the sample was aged until 180 days.



(a)



(b)

FIGURE 8. Influence of Kraft paper on acidity, mg KOH/g (a) Acidity, mg KOH/g with the presence of Kraft Paper (b) Acidity, mg KOH/g without the presence of Kraft paper

EFFECT ON TENSILE STRENGTH

Tensile strength is maximum tensile force per unit width that a paper and board can withstand before breaking. In order to understand the effects of Kraft paper in vegetable oils, the tensile strength was determined using 500 kN Universal Testing Machine. The crosshead speed and full-scale load range were set to 20 mm/min and 0.5 kN. The gap distance and width of the samples used for the test were $180 \text{ mm} \pm 1 \text{ mm}$ and $20 \text{ mm} \pm 0.1 \text{ mm}$. The results are shown below.

Figure 9 shows the effect of vegetable oils on tensile strength. Transformers ability become efficient and can operate economically when they have good tensile strength (Costanzo et al. 1999). The most critical aspect of the ageing process of solid insulation is reduction of its

mechanical strength. Once the cellulose numbers have fallen below a critical level, the transformer is at risk from the mechanical forces arising under short circuit or even during normal operation of the transformer (Shah & Tahir 2014).

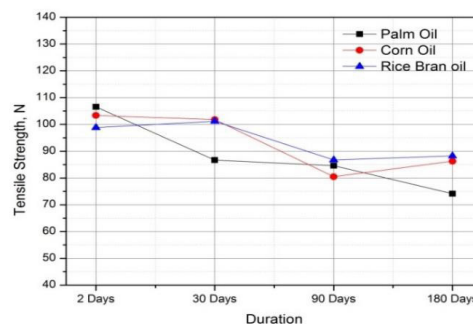


FIGURE 9. Effect vegetable oils on tensile strength

As we can see from Figure 9, the tensile strength of all samples in vegetable oils experienced reductions when the time of ageing increases. The palm oil is the higher experienced in reduction, 32% when it reached 180 days. Followed by corn oil, 17% and rice bran oil, 10%. Moisture content is one of the degradation product of cellulosic materials and major amount of moisture present due to material from outside and retained water in the Kraft paper. Acids were also produced during oil ageing and increase Kraft paper degradation and attack metallic parts in the transformer (Shah & Tahir 2011).

CONCLUSION

In this article, we have studied the influence of Kraft paper to various vegetable oils after having ageing time up until 180 days. In this case, we separate the sample in two methods, with presence of Kraft paper and without presence of Kraft paper. Through laboratory testing and subsequent analysis of the result, a series of conclusions were obtained. Experimental results show that the AC breakdown with the presence of Kraft paper was easier to breakdown than without the presence of Kraft paper because of the existence of moisture content from the cellulosic material from Kraft paper but after increased in ageing time, the Kraft paper absorbs the water which lowers the moisture in oil and make the AC breakdown become higher.

A high dielectric loss implies a low resistivity, so this property was also measured at both polarities. Vegetable oils bond with cellulose insulation and protect the cellulose from absorbing water. From that oil degradation mechanism creates acids and polar compound, which increase dielectric

losses and acidity. Cellulose and oil itself will increase the concentration of polar compounds and cause the increase in dielectric losses. Based on that, the results of dielectric losses with the presence of Kraft paper were higher than without the presence of Kraft paper. The results will cause the resistivity to become lower which is not good to the transformer. Good transformers will have high resistivity.

ACKNOWLEDGEMENT

The authors gracefully acknowledge the National Defence University of Malaysia for the funding.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

- Abdelmalik, A.A., Fotrhergill, J.C. & Dodd, S.J. 2013. Aging of Kraft paper insulation in natural ester dielectric fluid. *IEEE International Conference on Solid Dielectrics*, June. Bologna, Italy.
- Ariffin, M.M., Ishak, M.T., Hamid., M.H.A., Katim, N.I.A., Ishak, A.M. & Azis, N.A. 2017. Ageing effect of vegetable oils impregnated paper in transformer application. *International Conference on High Voltage Engineering and Power System*, 2-5 October, Bali, Indonesia.
- Carcedo, J., Fernandez, I., Delgado, A., Renedo, C., J. & Arroyo, A. 2016. Quantitative study on the aging of Kraft paper in vegetable oils. *IEEE Electrical Insulation Magazine* 32(6): 29-35.
- Carcedo, J., Fernandez, I., Ortiz, A., Delgado, F., Renedo, C. J. & Pesquera, C. 2015. Ageing assessment of dielectric vegetable oils. *IEEE Electrical Insulation Magazine* 31(6):13-21.
- Costanzo, A., Graziani, G. & Orsi, G. 1999. Driving ergonomics: New methodology for the assessment of stresses on upper limbs. *Safety Science Monitor* 3(2): 1-11.
- Choi, S.H. & Huh, S.C. 2013. Analysis of the chemical and electrical characteristic of vegetable oils exposed to accelerated aging. *2nd International Conference on Innovations in Electrical and Civil Engineering (ICIECE '2013')*.
- Garcis, B.G.T., Primo, V., Burgos, J.C. & Urquiza, D. 2017. Studying the loss of life of natural-ester-filled transformer insulation: Impact of moisture on aging rate of paper. *IEEE Electrical Insulation Magazine* 33(1):15-23.
- Haramija, V., Vrsaljko, D., Durina.V. & Vrsaljko, D. 2014. Thermal properties of synthetic ester-based transformer oil during ageing in laboratory conditions. *IEEE International Conference on Liquid Dielectrics*, Bled, Slovenia, 30 June- 3 July.
- Liao, R., Liang, S., Sun, C., Yang, L. & Sun, H. 2010. A comparative study of thermal aging of insulation paper impregnated in natural ester and in mineral oil. *European Transactions on Electrical Power* 20: 518-533.
- Martin, D., Khan, I., Dai, J. & Wang, Z. 2006. An overview of the suitability of vegetable oils dielectrics for use in large power transformers. *Euro TechCon* 1-23.
- Mcshane, C.P., Rapp, K.J., Corkran, J.L., Gauger, G.A. & Luksich, J. 2001. Paper insulation in natural ester dielectric fluid. 2001 *IEEE/PES Transmission and Distribution Conference and Exposition. Developing New Perspectives* 675-679.
- Shah, Z.H. & Tahir, Q.A. 2011. Dielectric properties of vegetable oils. *Journal Scientific Research* 3(3): 481-492.