Breakdown voltage of palm oil insulation enhanced with rice husk powder

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ABSTRACT Palm oil (PO) is a potential alternative to mineral oil for electrical insulation and has previously been studied with rice husk (RH) powder as a filler. Research has shown that RH powder enhances the breakdown voltage (BDV) and hence the dielectric, and physical properties of PO. Additionally, the effect of different preparation methods has been explored, showing further improvements in these properties. In this study, we modified the preparation method by scaling up the sample volume from 500 ml to 800 ml, leading to a positive impact on the properties of PO. To determine the optimal RH concentration for achieving the highest BDV, various concentrations of RH in PO were tested according to the IEC 60156 standard. The results demonstrate that the BDV improved significantly with the 800 ml sample volume compared to previous studies. Moreover, the data revealed a maximum curve trendline in the graph of BDV versus RH concentration. Overall, the modified preparation method yielded better BDV results, with the optimal RH concentration found to be 0.20 g/L, providing the highest BDV value.

KEYWORDS: Palm oil; High voltage; Insulation; Rice husk powder; Dielectric
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Short Communication

INTRODUCTION

Mineral oil (MO) has been reported to be used as a dielectric coolant in a transformer by General Electric in 1892 (McShane, 2002) and currently MO is in use in modern-day transformers. Alternative electrical insulation oil is needed to replace mineral-based oil insulation. This is because of the nature of MO itself that is hazardous and can contaminate the water if there is spillage, besides being non-biodegradable (Oommen, 2002). Biodegradability is the measure of a chemical decomposition by microorganisms over a period of 28 days according to the OECD 301 guideline (Tokunaga *et al.*, 2019). From the research, it is found that natural ester oils biodegrade the fastest as compared to mineral oils, hence it is suitable as an alternative to MO as insulating oil.

Naturally occurring esters, or natural esters (NE), are fats and oils obtained from animals and plants (O'Brien, 2009). NEs are the chemical combination of three fatty acids (oleic acid, linoleic acid and linolenic acid) with one molecule of glycerol which forms triglycerides (Tenbohlen & Koch, 2010). NE can be obtained from edible seed oils (McShane, 2002) such as sunflower oil, sesame and palm oil (PO) (Bakrutheen *et al.*, 2018). PO is extracted from the mesocarp tissues of palm fruits, and it is edible due to its high saturated fat content (Murphy *et al.*, 2021). In commercial usage, PO-based NE has been used by Fuji Electric, Tokyo, as insulating oil in their transformers (Ohki, 2018).

One of the most important characteristics that needs to be measured in electrical insulation oil is the breakdown voltage, BDV. The standard in IEC 60156 mentions that the minimum BDV limit for use as a transformer electrical insulating liquid is 30 kV (Mehta *et al.*, 2016). According to Calcara *et al.* (2019), electrical breakdown occurs when electrons are emitted from the cathode, leading to streamer formation. The authors claim these processes are not affected by the nature of the liquid dielectric but are influenced by the local electric field at the cathode surface. After the electrons have left the metallic surface of the cathode, the nature of the liquid dielectric will then become influential.

Fillers have been used to improve the workability of electrical insulating oil, such as TiO2, Fe3O4, Al2O3, ZnO and SiO2 (Junian *et al.*, 2021a). The stability of these suspended particles in the oil is influenced by both the attractive and repulsive forces between the charges on the filler particles. According to the DLVO theory, named after the scientists who postulate it - Derjaguin, Landau, Verwey and Overbeek, a stable particles suspension is achieved when the electrostatic repulsive force and the van der Waals attractive force is balanced (Jacob *et al.*, 2020). When the particle concentration increases, the average distance of the particle separation decreases. Larger van der Waal attractive force is in effect when the separation distance is lower and overcomes electrostatic repulsive force which leads to particle agglomeration (Chakraborty & Panigrahi, 2020). Equation (1) relates the net force, F_n as follows.

$$F_n = F_r - F_a \tag{1}$$

F_r refers to the electrostatic repulsive force and F_a is the van der Waal attractive force. When F_a is larger than F_r, F_n would be negative and thus the probability of agglomeration is high (Jacob *et al.*, 2020).

The reported BDV increments for vegetable oils with fillers typically fall below 100%. For example, mineral oil with Fe_3O_4 fillers showed BDV increments at concentrations of 0.05 g/L, 0.20 g/L, 0.30 g/L, and 0.4 g/L by 28 %, 57 %, 75 %, and 109 %, respectively (Khaled & Beroual, 2019). However, when the same fillers were added to natural ester oil (MIDEL 1204), which has a BDV of 69.2 kV for the unfilled oil, the improvements were smaller, with only 1.9% and 7.4% increases at concentrations of 0.30 g/L and 0.40 g/L, respectively. Although the effect of Fe_3O_4 in natural ester oil appears minimal, the BDV of the unfilled natural ester oil is already high (69.2 kV), surpassing the IEC 60156 standard. A study by Miya *et al.* (2023) also examined the BDV of MIDEL 1204, reporting a lower value of 30.6 kV, likely due to differences in preparation methods. With the addition of TiO_2 at 0.05 vol.%, the BDV increased to 56.6 kV, representing an 85 % improvement. Duzkaya and Beroual (2022) found that the BDV of MIDEL 1204, with a BDV of unfilled oil of 66.7 kV, improved by 7.8 % with 0.4 g/L of fullerene fillers.

In a study by Koutras *et al.* (2022), 37 %, 20 % and 10 % increments are obtained when SiC, ZnO and Al_2O_3, respectively, are used as fillers in Cargill's NEO FR3 natural ester oil which, for unfilled oil, has a BDV of 61.7 kV. Other studies have also demonstrated the effect of TiO_2 fillers on natural oils. For example, Yahya and Chik (2018) observed that the BDV of palm oil improved from 29.9 kV to 40.0 kV (a 34% increase) with the addition of TiO_2 fillers, while the BDV of coconut oil increased from 33.9 kV to 40.0 kV (an 18% improvement). Similarly, Oparanti *et al.* (2021) reported that the addition of SiO_2 fillers at a concentration of 0.5 wt.% raised the BDV of neem oil from 37.6 kV to 50.7 kV, marking a 35% increase. Despite these findings, current literature has yet to explore the use of natural fibres as fillers in insulating liquids.

Previous research has shown the improvement of using RH in improving PO in terms of dielectric and physical characteristics (Junian *et al.*, 2023; Junian *et al.*, 2021b). Preparation method also plays a large role in improving the BDV of PO with RH by almost 100 % as shown in Junian *et al.* (2023) using a direct mixture method. After PO of 500 ml is dried for 24 hours at 80 ˚C, filler (RH) is directly added without gap in time and the mixture is magnetically stirred for eight hours and left to rest for five hours before BDV test.

By adapting the direct mixture method described in Junian *et al.* (2023), a different preparation method is proposed in this paper, using 800 ml instead of 500 ml. There are two main objectives to be addressed: first, to analyse whether the BDV can be improved by using the modified preparation method adapted from Junian *et al.* (2023), and second, to determine if there is an optimal ratio of RH that gives the highest BDV value, as well as to observe if a trend exists at higher RH concentrations. Eight different concentrations of RH powder are used as filler in PO. The effect of these different concentrations on PO is evaluated using the BDV test. The results are tabulated and represented graphically with a trendline.

METHODOLOGY

Sample Preparation

Rice husk filler preparation

The rice husk (RH) filler is obtained from a local rice mill. The RH is washed with distilled water to remove impurities and then dried. Next, the dried RH is ground before it is sieved to the average size of 63 μm. The preparation flowchart of RH can be referred in (Junian *et al.*, 2023).

Palm oil with rice husk filler preparation

The preparation of palm oil (PO) with different concentrations (see Table 1) of rice husk (RH) filler is based on direct mixture method in (Junian *et al.*, 2023) with a slight change in the volume of PO. In this paper, 800 ml of PO is dried for 24 hours at 80 ˚C. The filler is added in the PO and the blend is stirred for 8 hours using a magnetic stirrer. PO without any filler is also prepared and it is simply referred as PO. Finally, the sample is left for 5 hours to be tested. Figures 1(a) - (h) show the samples prepared, and PO-U is untreated palm oil sample which did not undergo any drying process.

Table 1. Sample composition of palm oil (PO) and rice husk (RH).

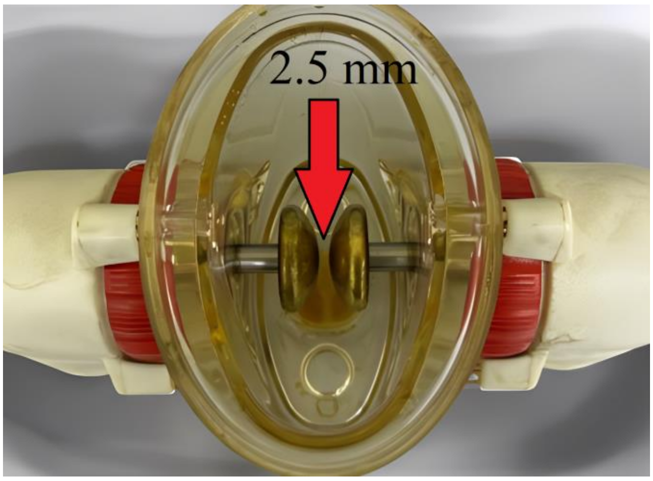
Sample	Amount of rice husk (g/L)
PO-U	0.00
PO	0.00
PO-0.05	0.05
PO-0.10	0.10
PO-0.20	0.20
PO-0.50	0.50
PO-1.00	1.00
PO-1.50	1.50
PO-1.75	1.75
PO-2.00	2.00

(a) (b) (c) (d) (e) (f) (g) (h)

Figure 1. The samples at concentrations (a) 0.05 g/L, (b) 0.10 g/L, (c) 0.20 g/L, (d) 0.50 g/L, (e) 1.00 g/L, (f) 1.50 g/L, (g) 1.75 g/L, (h) 2.00 g/L.

Electrical Characterisation of Palm Oil-Rice Husk Blend Samples

The BDV of the samples is measured using Megger OTS100AF Oil Tester shown in Figure 2(a) by using the standard IEC 60156. A 2.5 mm gap is set between two mushroom-shaped electrodes in Figure 1(b) which is verified using a Megger Thickness Tool. The oil chamber is filled with the sample and the BDV test is done with 18 readings taken. The results of all PO with different concentrations of RH are tabulated and graphed.



(a) (b)

Figure 2. The instruments (a) Megger OTS100AF Oil Tester, (b) oil chamber with mushroom-shaped electrodes for measuring BDV of the samples.

RESULT AND DISCUSSION

The mean breakdown voltage and increment (%) for all samples are shown in Table 2. The untreated sample (PO-U) and the no-filler sample (PO) have the lowest BDV values, and the data are taken for baseline references. When the RH concentration increases from 0.05 g/L to 0.20 g/L, there is a corresponding rise in BDV, with the highest improvement observed at 0.20 g/L. Beyond this concentration, however, the BDV starts to decrease, with the lowest improvement occurring at 1.75 g/L. Nevertheless, the addition of RH enhances the BDV strength of PO across all concentration. Figure 3(a) shows the curve derived from Table 2 (excluding PO-U) and the equation representing the maximum curve trendline is given in Equation (2).

$$y = -17.817x^6 + 134.94x^5 - 408.59x^4 + 628.73x^3 - 513.54x^2 + 195.4x + 62.278 \quad (2).$$

Table 2. Mean breakdown voltage (BDV) of palm oil at different concentrations of rice husk powder.

Sample	Mean breakdown voltage (kV)	Increment based from PO (%)	Standard deviation (kV)
PO-U	29.7	-	7.1
PO	59.0	0.00	6.4
PO-0.05	81.6	38.3	8.4
PO-0.10	89.2	51.2	9.3
PO-0.20	92.0	55.9	4.8
PO-0.50	84.0	42.4	5.7
PO-1.00	81.4	38.0	4.6
PO-1.50	74.7	26.6	7.9
PO-1.75	69.7	18.1	10.1
PO-2.00	71.8	21.7	6.2

The samples, PO and PO-U, exhibits lower BDV values than the samples with fillers, highlighting the critical role of fillers. Sample PO, which contains no filler, shows an improved BDV of 59 kV compared to PO-U, implying that drying process alone has a major effect. The drying process is applied to remove moisture (Makmud *et al.*, 2019), and it is proven that having less moisture via said process would yield better BDV values (Shurki *et al.*, 2019).

The positive correlation between RH concentration and BDV at lower concentrations (0.05 g/L to 0.20 g/L) can be explained by the theory proposed by Rajeswari *et al.* (2019). According to their research, RH particles act as traps for electrons when subjected to an electric field, reducing the movement of free electrons within the PO and consequently enhancing the insulating properties of the oil.

At higher concentrations, beyond 0.20 g/L, the BDV starts to decrease, likely due to particle agglomeration. This effect, observed in He *et al.* (2019), suggests that as more RH particles are added, they may cluster together, forming conductive pathways within the oil. Such agglomeration reduces the insulating effectiveness of the RH, leading to a decline in BDV. This trend aligns with the hypothesis that there is an optimal RH concentration for maximizing the BDV of PO.

In addition to the mean BDV data, the percentage increment in BDV as shown in Table 2, calculated relative to the unfilled PO with a BDV of 59.0 kV, follows the same trend shown in Figure 3(b). At all concentrations of rice husk in palm oil, the increments show to be positive, ranging from 18.1 % to 55.9 %. In the literature, the obtained increments are usually less for natural esters with fillers. The consistency in trendlines between the mean BDV and percentage increment data reinforces the conclusion that RH improves the dielectric strength of PO, but only up to an optimal concentration (around 0.20 g/L). This suggests that while RH particles can significantly enhance the insulating properties of PO, their concentration must be carefully controlled or else it would decrease the BDV of PO caused by particle agglomeration.

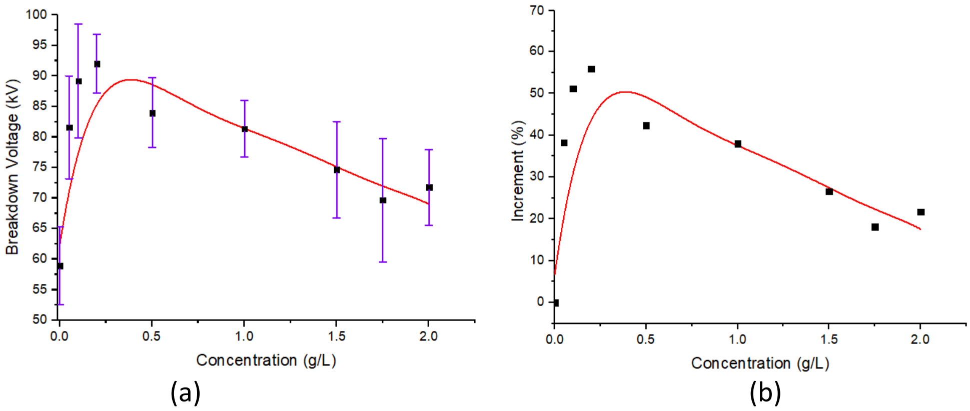


Figure 3. Graphs of (a) mean breakdown voltage (kV) with standard deviation (kV), (b) increment (%) of the breakdown voltage of palm oil at different concentrations of rice husk powder from 0.00 g/L to 2.00 g/L.

CONCLUSION

This research demonstrates that rice husk (RH) can enhance the breakdown voltage (BDV) strength of insulating oil across all tested concentrations when compared to unfilled palm oil (PO). By adapting a modified preparation method based on Junian *et al.* (2023) where 800 ml of PO is used instead of 500 ml, and following a careful mixing and resting process, the BDV of PO was improved significantly. The mean BDV values positively correlate with RH concentration up to 0.20 g/L where beyond this concentration, a decline in BDV is observed. This suggest that there is an optimal ratio for maximizing BDV which is likely due to particle agglomeration at higher RH levels.

While the findings support the improvement in BDV with the proposed preparation method, further research is necessary to uncover the underlying mechanisms that contribute to the observed trends in BDV in terms of dielectric permittivity, tangent delta and physicochemical properties. These additional investigations will help to establish correlations between these properties and the BDV, offering a more comprehensive understanding of the effectiveness of RH as a filler in PO.

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