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UNDERSTANDING THE DIELECTRIC CHARACTERISTICS OF BLEND OF RICE BRAN AND SUNFLOWER OIL

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Abstract

This work is completed to study the dielectric characteristics of blend of rice bran and sunflower oil. The unprocessed oil composition of 4:1 ratio of rice bran oil and sunflower oil is filtered using filter paper. The oil is heated to remove air bubbles and to remove impurities. Breakdown voltage test is conducted to check the breakdown voltage of the mixed oil using BDV kit. Tan delta test is performed by applying ac voltage to a test cell of known gap measuring the total current flow through the oil and separating and comparing the reactive and resistance portion of the current passing through the oil. The volume resistivity and dielectric constant of the oil is measured using Tan delta test. Dielectric test alone cannot determine the strength of the insulator oil hence an impulse test is performed to determine the ability of insulation to withstand transient voltages. In the AC breakdown study, RBO has the highest breakdown voltage for both test setups. PO is the second-best in AC breakdown voltage while MO shows the lowest breakdown voltage among oil samples. The percentage difference between using BAUR oil tester and BHT AC generator setup is between 4% and 10% at a 2.5 mm gap distance which is comparable for both types of equipment. For various gap distances studies, the breakdown voltage is increased with the increase of gap distance between the electrodes, for all oil samples. The Weibull distribution of MO, PO and RBO has well fitted with the fitting line of AC breakdown data. From the Weibull distribution, the empirical withstand voltages equations with gap distances of PO and RBO are derived.
Keywords: Breakdown voltage, Vegetable oil, Alternative oil ,Rice bran oil, Mineral oil

INTRODUCTION

Vegetable oil plays an important role in preparing food items that provide energy, micronutrients (vitamins), and fatty acids for humans to lead a healthy life. Oil in the food industry is utilized for frying, baking, storing, and to add aroma, colour, and texture to the food items. Fats and oils are basically triesters of glycerol with long-chain fatty acids called triglycerides. On repeated heating near frying temperatures, non-volatile toxic compounds are formed. Peroxides are the primary oxidized products produced, which on further heating get degraded to aldehydes, ketones, esters, etc., which are secondary products. Other chemical reactions like hydrolysis and polymerization produce monomers, dimers, trimers, oligomers, free fatty acids (FFA), and water to make oil into a highly tarnished product The different chemical compositions in oil undergo changes on degradation. Hence, oil quality analyses are being carried out in the quantification of degraded products using methods such as chromatography and spectroscopic methods like Fourier transform IR (FTIR), Nuclear Magnetic Resonance (NMR), Raman spectra, etc. To perform the analytical exploration, the oil has to be dissolved in organic solvents like benzene, acetone, etc. These solvents pollute the environment; moreover, the methods are time consuming and not economical.

Simple physical and chemical indices can be used for the quality assessment of oil and to quantify the toxic degraded products produced in the oil during successive heating.Dielectric constant ε_r (permittivity) is a measure of polar compounds and water content in the oil. Although FFA was taken as an index of degradation since 1981, dielectric constant is being used as the primary index of oil quality. This is due to the fact that degraded products such as peroxides, FFA, monomers, and other non-volatile complex compounds add polar molecules to the oil. In the presence of an external electric field, these polar compounds change the dielectric nature and capacitive value of a parallel-plate capacitor. The dielectric constant of unheated refined oil ranges from 1.5 to 2.9 at 2 Mega Hertz (MHz).The dielectric constants of oils are generally measured using the capacitive method, which is by measuring the ratio of the capacitance in the oil to that of the air. The higher the level of degraded products in oil, the higher is the increase in the dielectric constant. For example, increased quantities of ester, the second degraded product, lead to an increase in permittivity to 3.2.

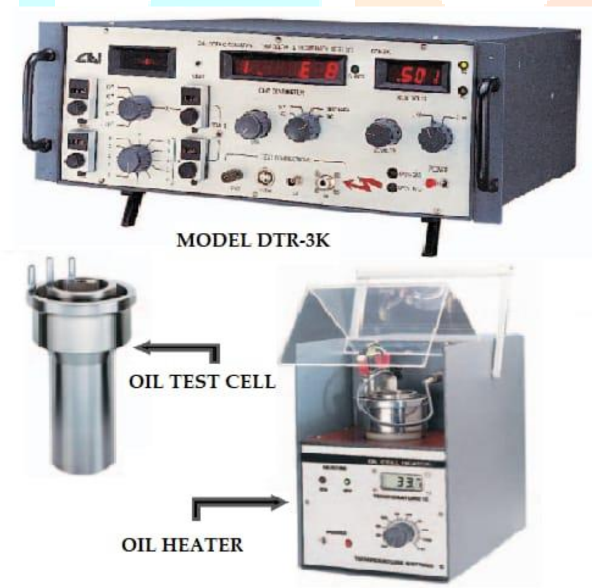


Fig 1: Block Diagram

Resistance of flow between successive layers in a liquid is the measure of viscosity of the sample. Viscosity is a measure of polyunsaturated fatty acid (PUFA) and monounsaturated fatty acids (MUFA) in the oil. The higher the content of unsaturated fatty acids, the lower is the viscosity The viscosity parameter also states the measure of saturated fatty acids, which is one of the degraded products. Hence, this parameter is highly related to the molecular structure of the liquid The measures of carboxylic group acid value (AV), peroxide value (PV), FFA, and long-chain unsaturated fatty acids like iodine value (IV) and saponification value (SV) provide the basic chemical quality indices of the oil.

LITERATURE REVIEW

Another potential vegetable oil that might be considered is Rice Oil, also called rice bran oil (RBO). RBO is extensively used in Asian countries [8]. RBO as a by-product of rice milling is obtained from the outer layer of the brown rice kernel accounting for 6–8% of the paddy rice. The global paddy rice production was 741 million tons and this huge amount of production resulted in more than 50 million tons of rice bran oil in 2014. Rice bran oil is widely used for various purposes such as cooking, fuel, and biodiesel but not in transformers until now. Only limited numbers of studies were done on RBO especially on the physical, chemical, and electrical properties. In 2016, S. Senthil Kumar investigated rice bran oil (RBO) for the ability to be used as alternative transformer oil. The initial study showed that the AC breakdown voltage under 2.5 mm gap distance of RBO has comparable performance to other natural esters [9]. The finding observed that RBO has better properties than other vegetable oils. However, the properties as permittivity, resistivity, and dissipation factor of RBO still lacking until now.

Some researchers reported that the dielectric strength of mineral oil (in kV/mm) decreases as the distance between the electrodes increases [10]. The previous studies for PO and RBO have only considered the AC dielectric strength of oils using small electrode gaps (1–2.5 mm). A transformer is usually composed of three-phase high-voltage windings, low-voltage windings, and probably tertiary windings. These windings can be made in the structures of disk or layer, of which each consists of many papers wrapped turn conductors. The turn-to-turn insulation is made by multiple layer oil-impregnated papers with a thickness of ∼1–2 mm. Washers are used to separate the disk conductors and thus oil ducts are formed between the disks with a thickness of ∼3–10 mm. The distance between windings is relatively large, which could be tens of mm. Therefore, it is necessary to investigate the AC strengths of the PO and RBO using larger electrode gaps.

Taking AC breakdown voltage of the oil as numerical value without knowing details of test conditions can lead to the wrong estimation in insulation systems design. Many factors like size of electrodes, area of electrodes, impurities present within the oil will affect the breakdown strength of the oil. Besides that, the condition of test equipment, the gap between electrodes, the material of electrodes and the volume of oil will also greatly influence the dielectric strength of insulation oil.

Therefore, in this paper, a detailed study of electrical properties such as permittivity, resistivity and tan delta is carried out to know the capability of RBO to meet the industrial standard. Besides that, an AC breakdown test, especially under larger gap distances (up to 10 mm), is also observed. The study also investigates the effect of different test equipment on the AC breakdown voltage of oil samples. The different test equipment will have different volumes of oil and different electrode materials. The effect of the stirrer in the testing is also being investigated. The MO is used in this study for comparison purposes.

METHODS

The AC breakdown test was performed using BAUR DTA 100C with a maximum output voltage of 100 kV. Fig. 2 illustrates the horizontal VDE configuration that was installed in the AC breakdown test equipment. This VDE (mushroom to mushroom) configuration testing represents a quasi-uniform field. The AC breakdown voltage was tested under a 2.5 mm gap distance, set up in a cubic glass with a volume of 400 ml according to the IEC 60156 standard. The rate of voltage rise was set at 2 KV/s and fixed initial standing time of 5 min before voltage application. The time interval was set at 2 min. A total of 50 readings on breakdowns were obtained for each sample. The tests were conducted at atmospheric pressure and room temperature (23–26 °C). The AC breakdown tester applied AC voltage across the test cell, filled with oil samples at a 50 Hz frequency.

The Weibull distribution is a well-known method for determining the probability distribution of breakdown voltages. This reliability technique is used to simulate the material strength and time to failure of components in an electrical or mechanical system. The breakdown voltage is used to fit the Weibull distribution curve and from the curve a 1% breakdown probability (withstand voltage is a statistically distributed quantity that corresponds to a failure probability. The failure probability depends on the electrical stress applied in the liquid. Normally, the Weibull distribution approach is generally accepted in the field of electrical insulation as the one that best fit the data approximating the failure and dielectric strength. Therefore, the Weibull distribution with two parameters (α and β) is used in this study. The breakdown voltages data were) and 50% breakdown probability (mean) can be determined. The cumulative function of Weibull distribution is given in Equation, where α is the scale parameter and β is the shape parameter.

Dielectric dissipation factor (DDF) or sometimes referred to as tan δ is a measure of the total current flow through the oil. If the insulating oil is free from impurities such as moisture, contaminants and oxidation by-products in the oil, the oil closely demonstrates the properties of perfect insulation (no current will flow through the oil). It is important to note that a very low DDF (decimal values up to 0.005) indicates excellent insulating oil. Besides, DDF is also highly dependent upon the temperature of the insulating oil and will increase with increasing temperature. Relative permittivity is an important parameter that shows how the oil behaves in an electrical field. In simpler words, relative permittivity, also called dielectric constant, indicates how easily a material becomes polarized by the imposition of an electric field on an insulator. Therefore, relative permittivity indicates the ability of the dielectric to polarize and acquire electrical capacity. Specific resistivity is another important electrical property of insulating oils and is given in units of Ωm (ohm-meters) or Ωcm (ohm-centimeters). Insulating oil that has a very high resistivity indicates a low number of free ions, ion-forming particles, and a low concentration of conductive contaminants. The resistivity of oil will decrease with the increase in temperature.

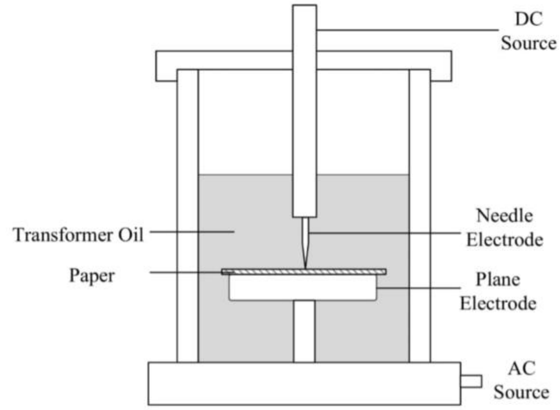


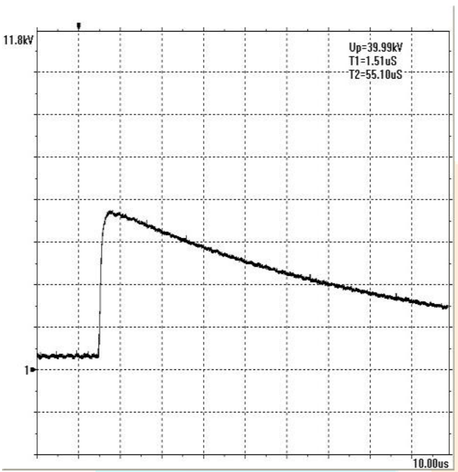
Fig 2: Work Flow diagram

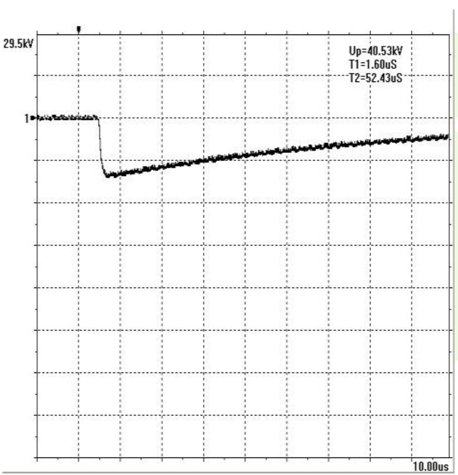
The dielectric dissipation factor, relative permittivity and resistivity of MO, PO and RBO can be seen At 90 °C, RBO has a 0.02168 dissipation factor which is 7 times higher than mineral oil (0.00322). Whereas the PO's dissipation factor is 12 times higher than mineral oil at 0.03846. Based on IEC 60247, all the oil samples fulfilled the requirement for transformer liquid insulation for DDF values which is less than 0.005 for MO and less than 0.05 for vegetable oil. The higher dissipation factor value of vegetable oils is due to the molecular structure of vegetable oil which has a slightly more polar character compared to mineral oil. Among vegetable oils, RBO has a lower DDF value than PO which can relate to RBO having lower fatty saturated acids (20%) compared to PO (50%) in their molecular structure.

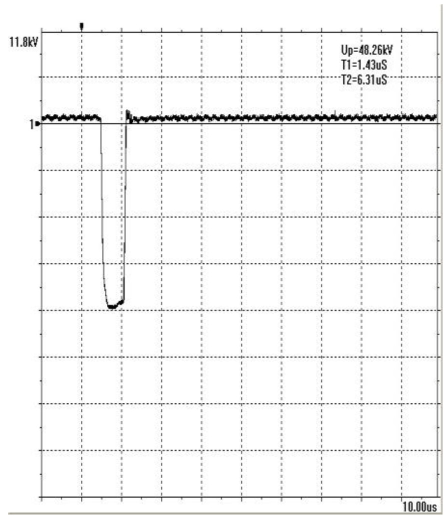
RESULTS AND DISCUSSION

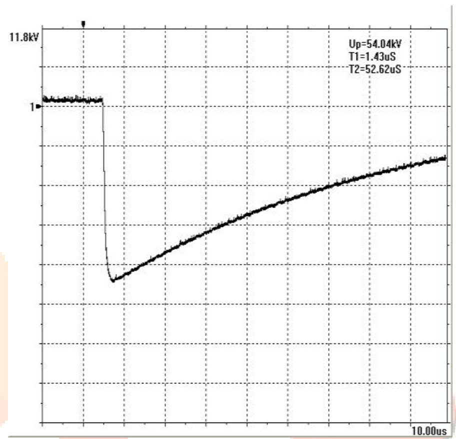
Illustrates the variation of the dielectric constant of the samples, which ranges from 3.5 to 1.2. Comparing the dielectric constant of modified RBO, ε_r of heated oil increases by 17%, ε_r of the mixture of oxidized and unheated oil increases by 11%, and a mixture with monounsaturated oleic decreases by 5%. On the other hand, if the behaviour of the modified MO is analysed, ε_r of heated oil increases by 4.7%, the mixture of heated and unheated oil increases by 8.7%, and addition with oleic acid decreases by 8.3%. Relating RBO with MO, the increase in ε_r of heated oil is more for RBO as it has 47% of PUFA whereas MO has 21% of PUFA. The study also elucidates that the larger the number of unsaturated double bonds, the faster it gets oxidized to a single bond with the addition of hydrogen.The mixture of oil with monounsaturated oleic acid decreases the dielectric constant value. Hence, the higher the percentage of unsaturated fatty acids, the smaller would be the dielectric constant value. These measurements support the factor that it could be used as an index in the quality analysis of the oil.

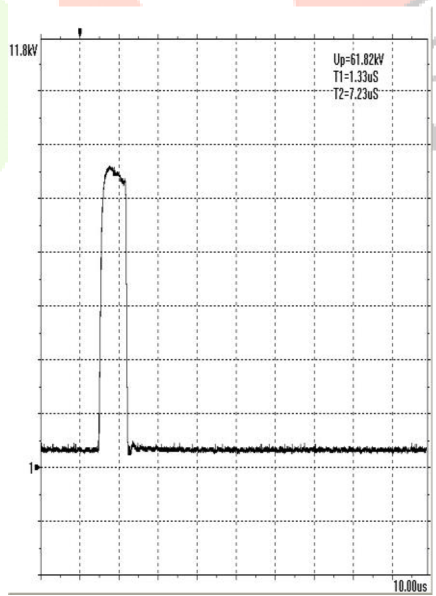
The variation of dielectric constant with temperature is related using a combination of linear, quadratic, and non-linear Akerlof and Oshry's Model as shown illustrates the correlation analysis for the modified oil samples. The regression coefficient R^2 value is observed to exhibit the best fit of the equation as the value ranges between 0.990 and 0.997. The SEE values exemplify that the deviation between the computed and experimental values is less than 1.2%. From the values of scaling coefficient *A*, *B*, *C*, and *D* values of dielectric constant at any desired temperature can be predicted. Linear equation.











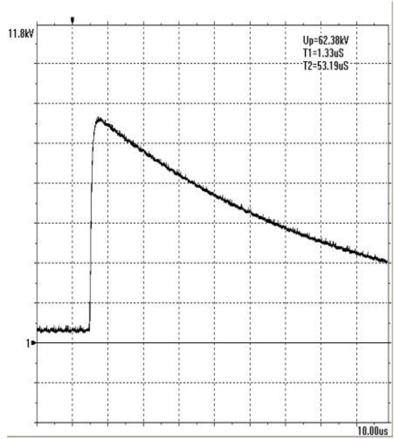
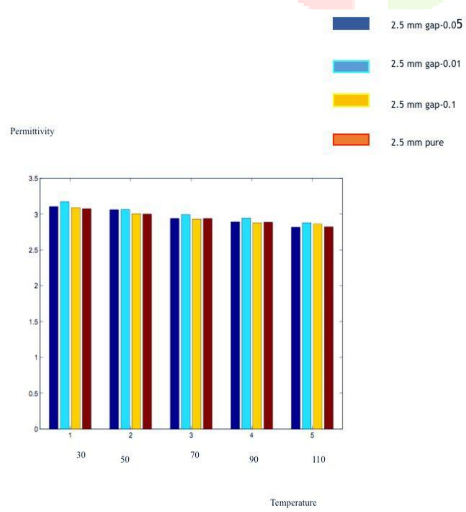


Fig 3: Voltage Analysis

The quality of the modified oil can be estimated from the change in the molecular structure, which in turn is categorized by the change in energy of intermolecular bonding. The unsaturated fatty acids exhibit cis isomerism; hence the bonding is not stronger. These molecules can be easily agitated using temperature. In the food industry, only viscosity can be used as an index to estimate the quality of oil. Viscosity is one of the testing methods used at factories in the nations of the Commonwealth of Independent States (CIS).

The above-mentioned two non-invasive methods in determining the quality of oil highly depend on its total peroxide content (TPC) Both dielectric constant and viscosity decrease non-linearly with temperature. Viscosity of oil represents the flow property, which can be related to the activation energies of movement and the orientation of dipoles with respect to temperature. A combination of these two physical characteristics keeping temperature as the independent parameter is illustrated in Table 6. A novel equation using the logarithmic relation to relate the two dependent properties is as follows:



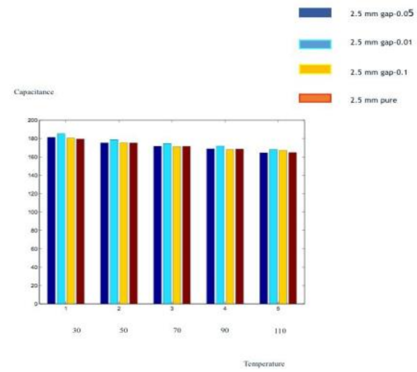


Fig 4: Result Analysis

This can also be used to predict the IV of oil for the quality analysis independent of temperature. RBO and MO contain more than 75% of long-chain unsaturated fatty acids. When oil gets oxidized, the unsaturated fatty acids get saturated due to the addition of hydrogen in the double bond and increase the quantity of FFA. The quantification of SV is the index of available long-chain fatty acids and the possibility of using oil in successive frying. During frying, oil gets degraded due to successive heating and chemical breakdown.

The impact of the degree of oxidation in heated oil, oil mixed with heated oil, and added with oleic acid was investigated. During oxidation, the IV value of heated RBO is 99.8, which changes to 102.8 with the mixture of heated and unheated oil. The value still increases to 109 with the addition of 20% of oleic acid with the oil. The heated MO has an IV value of 95, which increases to 98 for the mixture of heated and unheated oil and still increases to 101 with the addition of MUFA (oleic acid). Table 7 illustrates the variation of the chemical and physical indices of the modified oil. According to the literature survey, the dielectric constant of oil highly depends on the unsaturated fatty acids (IV value)

Conclusion

The current study elucidates that both permittivity and viscosity of oil are properties that depend on the measure of unsaturated fatty acids. These properties of modified oil were observed to decrease with increase in temperature. This non-linear variation was fitted with empirical equations to predict the data in the intermediate temperature. Akerlof and Oshry’s Model had prodigious R^2 ($R^2 > 0.990$) within the temperature range of 30–75°C. From the non-linear correlation equations that relate viscosity with temperature, Wright’s ASTM Model exhibited high R^2 ($R^2 > 0.990$) for all modified oils within the temperature range of 30–75°C. The chemical indices like SV, IV, FFA, AV, and PV were measured for every modified sample. To switch over from chemical analysis, the indices were correlated with the electrical property of the oil. The dependency factor R^2 computed between dielectric constant with SV, IV, and PV ranges from 0.936 to 0.995. From the analysis, it was shown that chemical changes that take place in oil deterioration can be analysed using the electrical property. The study also indicates that RBO and its mixture exemplify more sustainability of unsaturated fatty acids compared to MO. The experiment elucidates that RBO has more oxidative stability compared to MO.

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