BREAKDOWN STRENGTH MEASUREMENTS OF BIODEGRADABLE INSULATING OILS UNDER ELEVATED POWER FREQUENCY VOLTAGE

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Abstract: This paper presents the experimental results of breakdown strength of biodegradable insulating oils under the application of elevated power frequency voltage. Breakdown voltage measurements were performed using a special device at room temperature. The electrodes were Rogowski type according to IEC 60156:1995 and the gap spacing varied from 1mm to 2.5mm. Thus the electric field between the electrodes was approximately homogeneous. The amplitude of power frequency voltage was increased with four different rates, 0.5kV/s, 1kV/s, 2kV/s and 5kV/s. The measurements were divided into cycles. Each cycle of measurements corresponded to a different increasing rate of the voltage amplitude. The relaxation time between the measurement cycles was 0min, 5min and 10min and the electrodes were regularly polished in order to avoid any impact on the breakdown voltage by them. The measurements were performed on different days and consequently the humidity varied between 33% and 50%. This had an impact on the breakdown of the insulating oil as indicated by the measurements. In some measurement cycles the oil was heated up in order to investigate the impact of temperature on breakdown voltage.

1 INTRODUCTION

It is well known that liquid dielectrics are widely used in Power Systems as insulation in transformers, cables, circuit breakers etc. The most common liquid dielectric is mineral oil which has very good electrical and physical characteristics. However in the recent years natural ester and synthetic ester liquids are being proposed as potential alternatives to mineral oils because they are environmental friendly and they have higher fire safety. These liquids are widely used in distribution and traction transformers but they are not used in high voltage power transformers due to their inferior dielectric performance in comparison to mineral oils.

Studies concerning dielectric strength of esters under lightning impulse voltage and power frequency voltage have been made by several researchers in the last years [1-8]. Moreover a series of investigations have been made concerning moisture solubility, ageing, electrostatic charging tendency etc [7, 9, 11].

In the present paper we focused on the performance of ester oils when they are subjected to elevated power frequency voltage of different increasing rates. According to the IEC 60156 standards, breakdown strength of liquids is determined with the application of power frequency voltage with 2kV/s rising rate in homogeneous gap of 2,5mm length. Additional to this, three more increasing rates were applied during the experiments, 0.5kV/s, 1kV/s and 5kV/s and for different gap spacing.

The influence of water presence inside the oil, the heating up of the oil and the relaxation time between the applications of the voltage were also investigated during the experiments, for each increasing rate separately.

2 EXPERIMENTAL DESCRIPTION

The ester oil we used during the experiments was the natural ester FR3 (Cooper), which is refined from soya bean and its main molecular component is triglyceride-fatty acid ester, which contains a mixture of saturated and unsaturated fatty acids with up to 22 carbon length chains containing 1 to 3 double bonds [7, 9, 10]. FR3 is more polar than mineral oil, and has higher relative permittivity and lower volume resistivity than mineral oil.

We used an automatic insulating oil tester (Baur DTA 100). The test cell is made by glass with a volume of 400ml. The electrodes were Rogowski type according to IEC 60156:1995 and they were made of brass steel. The test cell with the electrodes is illustrated in Figure 1. Gap length varied between 1mm and 2.5mm. The power frequency voltage generator of oil tester was capable of producing up to 100kVrms with different rising rates 0.5kV/s, 1kV/s, 2kV/s and 5kV/s. The frequency of the voltage was 50Hz. A separate measurement setup is not necessary as the oil tester has its own measuring system for the measurement of breakdown voltage.

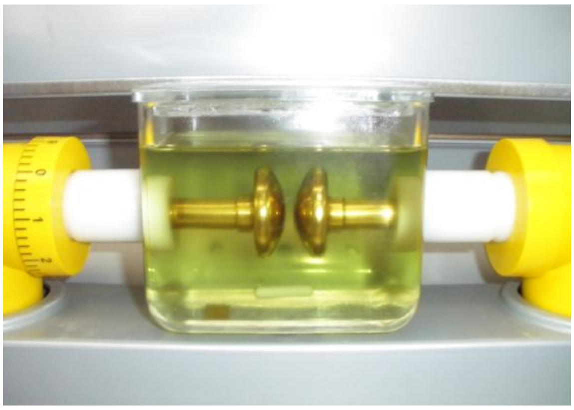


Figure 1: The test cell with the electrodes.

Special care was taken during the experiments in order to ensure that the oil will not be affected by humidity, oxidation and will not be contaminated by solid impurities. All the experiments were carried out at room temperature and ambient pressure.

The experiments were divided into sets of measurements. A set of measurements includes six voltage applications with a specific increasing rate. The relaxation time between the voltage applications was 2min, in order to let the discharge by-products and gas bubbles to diffuse. At the end of each set the mean breakdown voltage and standard deviation σ were calculated. The relaxation time between sets was 5min. During the measurements the oil was constantly agitated using a stirrer at the bottom of the cell. For the distance of 2.5mm, sometimes, the breakdown voltage was equal or higher than 100kV, so we interrupted the set.

3 EXPERIMENTAL RESULTS

3.1 Rising rate of voltage application

In the first part of the experiments the breakdown voltage of FR3 was measured under the application of power frequency voltage with four different rising rates. Gap space varied between 1mm and 2.5mm and the oil was new, free from water contamination and solid impurities. The results of the experiments are illustrated in Figures 2 to 5. The values of breakdown voltages in these Figures are the mean values of at least 20 sets.

As it was expected breakdown voltage increases with the gap space. In all cases, breakdown voltage increases with the increase of the rising rate of the applied voltage. One may conclude that fast rising voltages are less dangerous than slower ones.

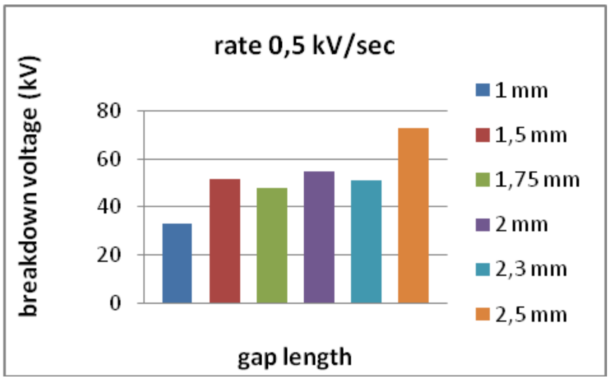


Figure 2: Breakdown voltage-rising rate 0.5kV/sec

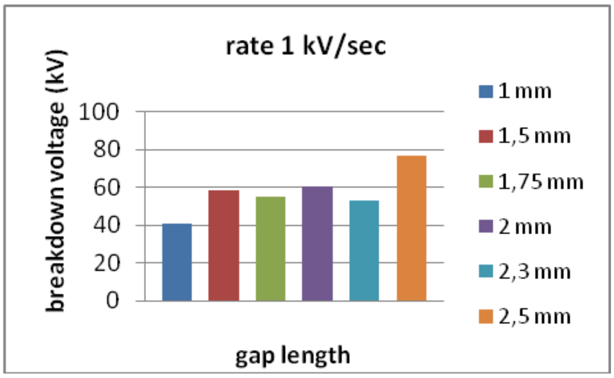


Figure 3: Breakdown voltage-rising rate 1kV/sec

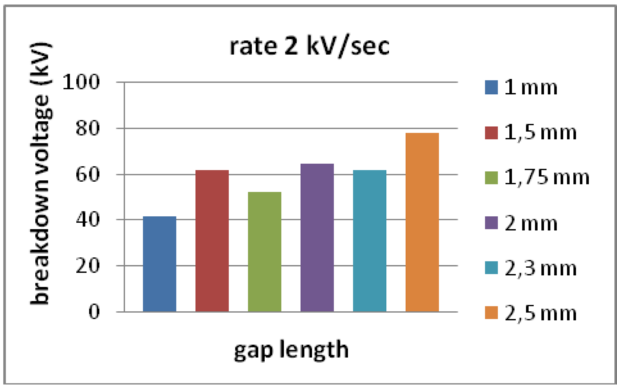


Figure 4: Breakdown voltage-rising rate 2kV/sec

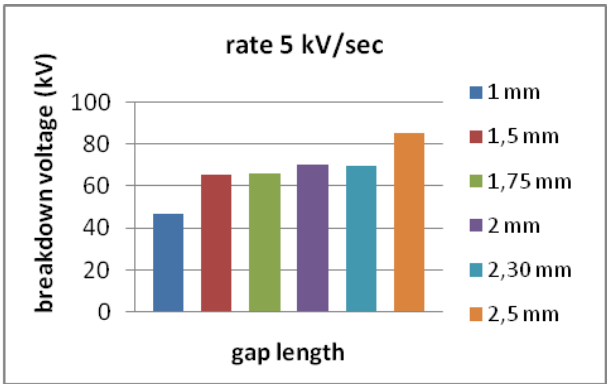


Figure 5: Breakdown voltage-rising rate 5kV/sec

3.2 Influence of relaxation time

Another parameter that was investigated during the experiments was the influence of the relaxation time between the sets of measurements. A relaxation time between the breakdowns is necessary for the breakdown by-products and gas bubbles to diffuse. In order to study the effect of different relaxation times on breakdown voltage the following procedure was conducted. For each rising time, several sets of measurements were obtained and the mean breakdown voltage was calculated. The relaxation time between the sets varied. There are results for 0min (continuous applications), 5min and 10min. The results are illustrated at Figures 6 to 9.

At Figures 6 to 8 the variation of mean breakdown voltages at every set of measurements is shown for different rising voltage rates. In Figure 9 the mean breakdown voltage from all the sets of measurements is illustrated for the different relaxation times and for the different rising voltage rates.

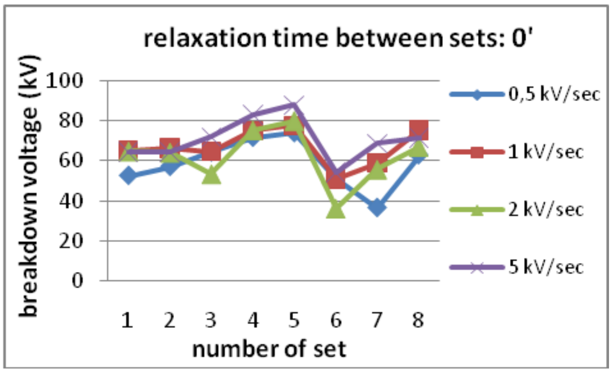


Figure 6: Breakdown voltage at each set for relaxation time equal to 0 minutes.

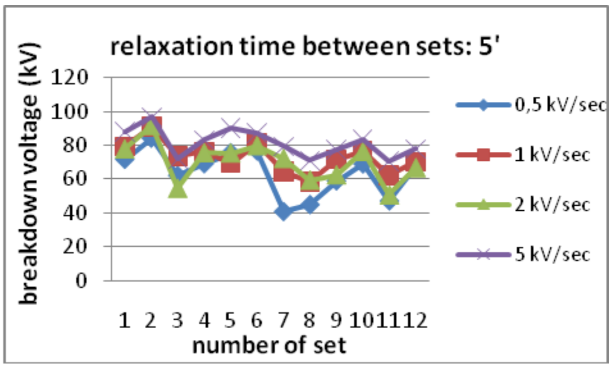


Figure 7: Breakdown voltage at each set for relaxation time equal to 5 minutes.

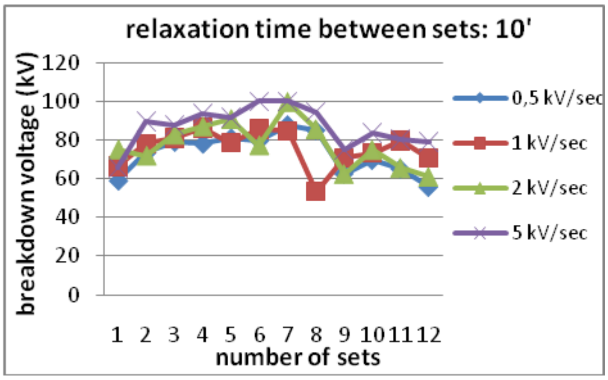
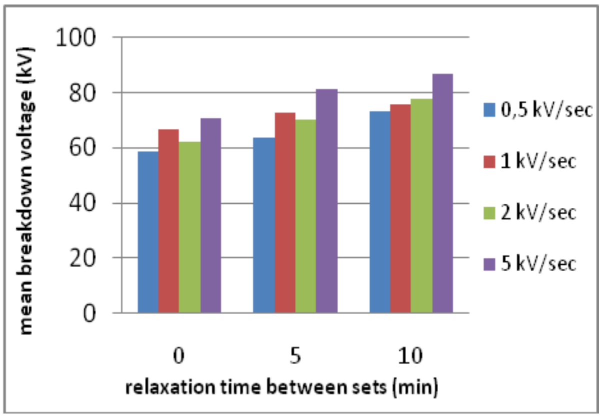


Figure 8: Breakdown voltage at each set for relaxation time equal to 10 minutes.



relaxation time	Mean breakdown voltage kV			
	0.5 kV/sec	1 kV/sec	2 kV/sec	5 kV/sec
0 min	58.7 kV	66.8 kV	62.2 kV	70.8 kV
5 min	63.8 kV	72.9 kV	70.3 kV	81.4 kV
10 min	73.0 kV	75.6 kV	77.8 kV	86.7 kV

Figure 9: Mean **b**reakdown voltages of all sets (Fig. 6-8) for different relaxation times and rising rates.

From the obtained results it is clear that the dielectric behaviour of the liquid is better with increased relaxation time, because breakdown by-products and gas bubbles have more time to diffuse. This increase of breakdown voltage is more intense for the lower and the higher rising rates, 0.5kV/sec and 5kV/sec respectively.

3.3 One day stress

In order to investigate the endurance of dielectric characteristics of the FR3 insulating oil and withstand to degradation after the occurrence of many electrical breakdowns the following experimental procedure was applied. The oil was subjected to continuous sets of measurements in a time period of 12 hours. The relaxation time between the sets was 10 minutes. The gap space was equal to 2.5mm and the rising rate equal to 2kV/cm. The results are illustrated at Figure 10. The oil has a steady behaviour and the breakdown strength is not affected by the continuous breakdowns. Moreover it seems that its behaviour is slightly better at the last sets. Mean breakdown voltage from all the sets is 83.5kV and it is clear that the breakdown voltage increases after the 10th set of measurements.

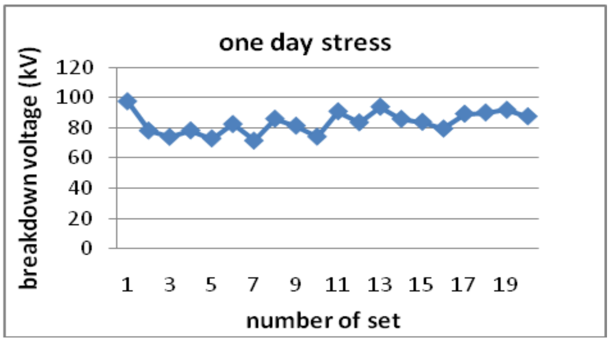


Figure 10: The variation of breakdown voltage during one day stress of the oil sample.

3.4 Temperature influence

At the last series of experiments we focused on the influence of the temperature on the dielectric strength of the natural ester oil. Three sets of measurements were conducted. In the first set the breakdown voltage of new, unused ester oil was obtained, at room temperature. The oil was heated up to 105^{o}C and the breakdown voltage was measured again. The same procedure was realized for oil that it was used earlier in other experiments and thus its breakdown strength was deteriorated. Moreover the oil was exposed for one week in atmospheric conditions. A third set of experiments was conducted for oil that was exposed to atmospheric conditions for more than one week. The results are illustrated at Figure 11. Table 1 shows some numerical results of temperature influence experiments.

Table 1: Mean breakdown voltage kV

New oil 2 kV/s		**Bad oil** 2kV/s	
24^{0}C	105^{0}C	25^{0}C	105^{0}C
93.7	95.0	33.9	83.5
93.0	>100	37.0	84.3
99.2	>100	37.7	80.5
>100	>100	44.2	79.8
>100	>100	35.3	73.9
>100	>100	40.2	89.5
95.3kV	**97.2kV**	**38.0kV**	**81.9kV**

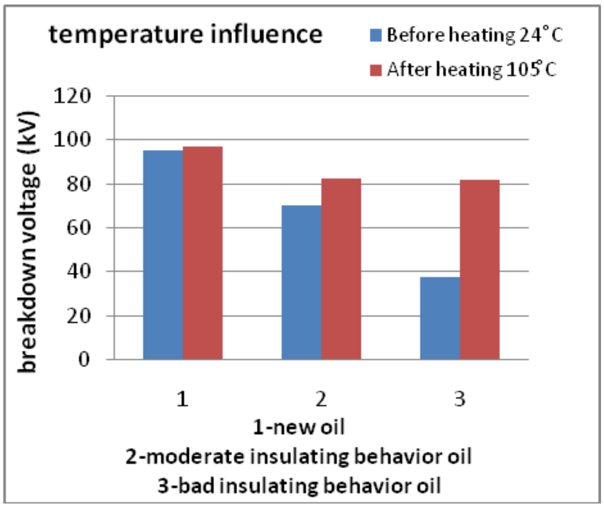


Figure 11: Temperature influence on breakdown voltage.

It is clear that the heating of the ester oil has a very positive impact on breakdown strength especially in the case of oil with bad insulating behaviour. One of the reasons may be that the oil heating removes the moisture.

4 CONCLUSION

Several characteristics of natural ester oil FR3 such as the influence of voltage rising rates, the relaxation time between the measurements, the endurance of the dielectric characteristics and the temperature influence on breakdown voltage were studied in the present paper.

Breakdown voltage depends on the rising rate of the applied voltage. It increases with the increase of the rising rate. It seems that voltages with slower rising rates are more crucial.

From the obtained results it is also clear that the dielectric behaviour of the natural ester oil is better with increased relaxation time, because breakdown by-products and gas bubbles have more time to diffuse.

The dielectric properties of the oil are essentially stable when it is subjected to continuous breakdowns for a long period of time. It seems that the continuous breakdowns with power frequency voltage did not produce significant decomposition products capable to reduce the breakdown strength of the oil. Ester oil is seriously affected by moisture. With the heating of the oil the moisture is removed and the breakdown voltage increases considerably.

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