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EXPERIMENTAL INVESTIGATION OF FACTORS AFFECTING THE BREAKDOWN VOLTAGE OF DIFFERENT SYNTHETIC INSULATING MATERIALS

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ABSTRACT

This paper reports an experimental investigation of the breakdown phenomena of perspex, bakelite and teflon as a synthetic insulating materials immersed in transformer oil. These samples of insulations were subjected to A.C. and D.C. voltages increased gradually to that limit at which breakdown takes place. Here also the effect of poth material thickness and electrode diameter were investigated beside the effect of ambient temperature. An attempt has been made to explain the decrease in breakdown voltage due to the increasing of ambient temperature. A mathematical expression was proposed to give the breakdown voltage of perspex, bakelite and teflon in terms of ambient temperature, electrode diameter and thickness of material. The constants related to each material and type of the applied voltage.

1. INTRODUCTION :

It has been established in recent years that the breakdown of solid insulation in diverging electric fields may occur by the action of successive discharges which cause a tree like structure of channels to propagate from the region of high electric stress into the body of the dielectric until a continuous conducting path is formed between the electrodes(1). Because of the formation of discharges depends on the temperature, it is necessary to study the effect of ambient temperature on the breakdown voltage of solid insulations. This work is aimed to study the effect of ambient temperature on the breakdown voltage of perspex, bakelite and teflon as synthetic insulating materials. The experiments were carried out in transformer oil on square specimens of the above mentioned materials. Each specimen has side of 5 cm and the thickness were varied to study the effect of thickness at different temperatures on the values of breakdown voltage. Here also, it has been demonstrated that the values of breakdown voltage were affected by the electrode diameter (2).

2. EXPERIMENTAL SET-UP AND PROCEDURE :

The rod-plate system is used to give inhomogeneous field. The specimens of perspex, bakelite and teflon were squares, each of 5 cm side and 4 mm thickness. The high voltage electrode is inserted in a 2 mm diameter hole of 2 mm depth at the centre of the specimen. The specimens were cleaned and dried before test to remove any traces of grease or fibers. Specimens and electrodes were immersed in a pirex vessel containing transformer oil to avoid any surface flashover on the surface of the specimen between the two electrodes. The transformer oil was replaced after every ten breakdowns. Figure (1) shows the test arrangements. Any value of the breakdown voltage given or mentioned here represents the mean value of five successive readings. The ambient temperature is increased from 25°C to 85°C, which represents the maximum allowed operating temperature for such insulating materials. The increasing of abmient temperature is obtained by using electric heater supplied from 220 volt supply to control the temperature through an auto transformer. The temperature is measured by thermometer having range of -10 to 100 °C. D.C. and A.C. high voltages are obtained using a high voltage generating circuit consisting mainly of a control unit, high voltage transformer, rectifier unit, smoothing capacitor and measuring unit. This circuit is supplied from a 220 V, 50 Hz supply. During all tests the applied high voltage is smoothly increased at a constant rate of 1 KV/sec and directly recorded by using an electrostatic voltmeter connected across a potential divider.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS :

The breakdown voltage of synthetic insulating materials is affected by many different factors. Some of these factors are related to the material it self and the others are related to the surrounding conditions. The present work is planned to investigate some of these factors which affect the breakdown voltage of synthetic insulating materials. The investigated factors include the type of applied voltage and its polarity, ambient temperatures, material type and thickness, and electrode diameter under inhomegeneous field conditions. The obtained experimental results are presented here under three subheading as follows :

3.1. Effect of Ambient Temperature on Breakdown Voltage :

The experimental results are given in Figs. (2) and (3) for sample of the three mentioned materials namely perspex, bakelite and teflon, where Fig.(2) represent the results under A.C. voltage and Fig. (3) represent the results under D.C. voltage. The D.C. voltage polarity gives higher breakdown voltage than that under A.C. voltage. The effect of the applied voltage on breakdown may be explained as follows :
The breakdown is initiated by surface discharges and the voltage at which is occurs is dependent on the energy content of each surface discharge as well as the number of surface discharges during the presence of the applied voltage [3]. As the duration of applied voltage increases, the number of surface discharges increase. Therefore discharges of smaller energy content, i.e. at a lower ap0lied voltage can cause breakdown. As the duration of applied voltage decreases, the number of discharges decrease, higher voltages being required to produce surface discharges of sufficient energy to cause breakdown. However in the case of D.C. voltage, the surface discharge inception occurs at very high voltage due to space charge effects leading to higher breakdown voltages.

It is seen from Fig.(3) that the breakdown voltages for negative polarity are always greater than those for positive polarity. A similar effect was discussed by Masson [4], in respect of breakdown in divergent fields. It is found that the same arguments hold good in respect of breakdown voltages also. From Figs (2 and 3) it can also be noticed that the values of breakdown voltage are affected strongly by the ambient temperature is increased.

Generally the breakdown voltage of the materials under test is reduced to about 75% of its initial value as the ambient temperature is increased from 30°C. The decrease in the breakdown voltage due to the temperature rise can be explained briefly as follows At high temperature, the thermal breakdown of synthetic insulation may occur. The heat generated by leakage currents, which increase with the temperature rise, will be partly conducted away from the specimen and partly absorbed to raise the lattice temperature. If the rate of heat generation at any point in the insulation exceeds that at which heat is conducted away from it, a condition of thermal instability may result and a thermal breakdown of the insulation occurs. An addition, the leakage currents and surface discharges result in electrochemical deterioration of the insulation (4).

3.2. Effect of Material Thickness on Breakdown Voltage :

The effect of material thickness on the breakdown voltage of the three mentioned materials is investigated carefully. It has been found that the breakdown voltage of synthetic insulating materials is also affected by the material thickness under both A.C. and D.C. high voltages. The breakdown voltage increases as the material thickness is increased. It is clearly seen in Figs(4 and 5) that samples of prespex give highest breakdown voltage while bakelite samples have the lowest breakdown voltage of the three materials under test. This fact is clearly illustrated in Figs (4 and 5) which show the relation between the breakdown voltage and material thickness under A.C. and D.C. respectively at 30°C and &=°C. It is clearly seen that the negative D.C. breakdown voltages are higher than both positive D.C. and A.C. voltages. Generally breakdown voltage increases as the material thickness is increased (5). The percentage increase in the breakdown voltage is generally about 150% as the material thickness is increased from 2 mm to 6 mm.

3.3. Effect of Electrode Diameter on Breakdown Voltage :

The breakdown voltage of the three materials under test is noticeably affected by the diameter of electrode. The obtained results are shown in Figs (6 and 7) which clearly illustrated that the breakdown voltage increases as the electrode diameter is increased These figures show the relation between the breakdown voltage with diameter of electrode under A.C. and D.C. voltages at 30°C and 60°C as an examples. It is also clearly seen that the negative D.C. breakdown are higher than those both under positive D.C. and A.C. voltages. The breakdown voltage increases as the electrode diameter is increased. The increase in the breakdown voltage due to the increasing of the electrode diameter is noticeable and can be calculated using the experimental results given in Figs(6 and 7). The percentage increase in the breakdown voltage due to the increase in the electrode diameter is in the range of up to 180% of the initial breakdown voltages as the electrode diameter is increased from 2 mm to 6 mm.

4. MATHEMATICAL TREATMENT :

In this section a mathematical expression is proposed to indicate the effect of ambient temperature, material thickness and electrode, material thickness and electrode diameter, on the breakdown voltage of synthetic insulating materials. In this treatment the "Least-Squares" method is used to find the mathematical expression for the relationship between the breakdown voltage of synthetic insulations and the ambient temperature, material thickness and electrode diameter. If (x) represents the ambient temperature in degrees or the diameter of electrode in millimeter or the thickness of specimen in millimeter, the breakdown voltage (V) in KV of perspex, bakelite and teflon can be determined by the following equation.

$$V = a x^{b}$$

Where a and b are constants depending on the type of both voltage and material. The following table gives the calculated values of these constants under three factors namely ambient temperature, electrode diameter and material thickness.

Type of Voltage	Type of Material	Ambient Temperature		Electrode Diameter		Material Thickness	
		a	b	a	b	a	b
A.C.	Perspex	75	-0.25	26	0.27	23.5	0.3
	Teflon	110	-0.4	20.2	0.36	20.9	0.32
	Bakelite	70	-0.3	20.5	0.32	17.0	0.35
D.C. Negative Polarity	Perspex	155	-0.35	31.5	0.3	33.5	0.28
	Teflon	106	-0.28	31.0	0.26	32.0	0.25
	Bakelite	115	-0.32	30.5	0.22	33.0	0.23
D.C. Positive Polarity	Perspex	80	-0.23	25.0	0.35	22.4	0.36
	Teflon	62	-0.2	25.5	0.28	20.0	0.38
	Bakelite	72	-0.27	19.5	0.4	23.7	0.26

5. CONCLUSIONS :

This experimental work can be concluded in brief as follows :

a. The breakdown voltage of the some selected synthetic materials decreases with the increasing of ambient temperatures.Breakdown in this case is thermal in its nature due to the leakage current, which increases rapidly as the ambient temperature is increased.

b. It has been found that the breakdown voltage of the mentioned materials increases with the increasing of both the electrode diameter and material thickness.

c. It has been demonstrated that breakdown voltage under negative polarity is higher than that under A.C. voltage and D.C. voltage of positive polarity.

d. As a proposed mathematical expression, the breakdown voltage of perspex, bakelite and teflon is given as an exponential function in terms of ambient temperature, electrode diameter and material thickness, and constants related to each material and the type of applied voltage.

e. The proposed mathematical expressions gives breakdown voltage values well agreeing with those obtained by experiments. The percentage deviation on applying this expression does not exceed ± 6% of the experimental values.

6. REFERENCES :

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1] High voltage electrode.
2- Specimen
3] Low voltage electrode.

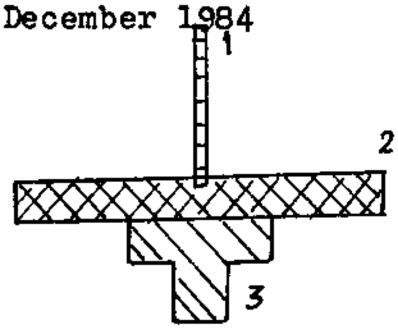


Fig.[1] Electrodes system configuration

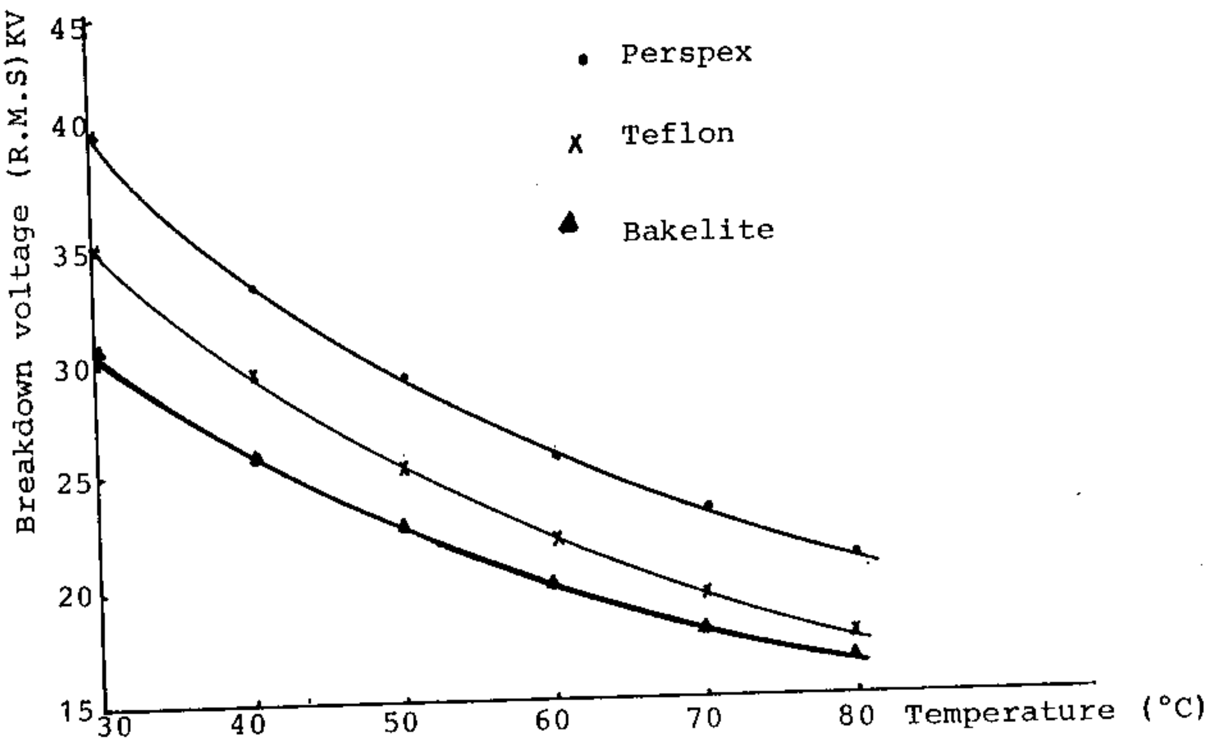
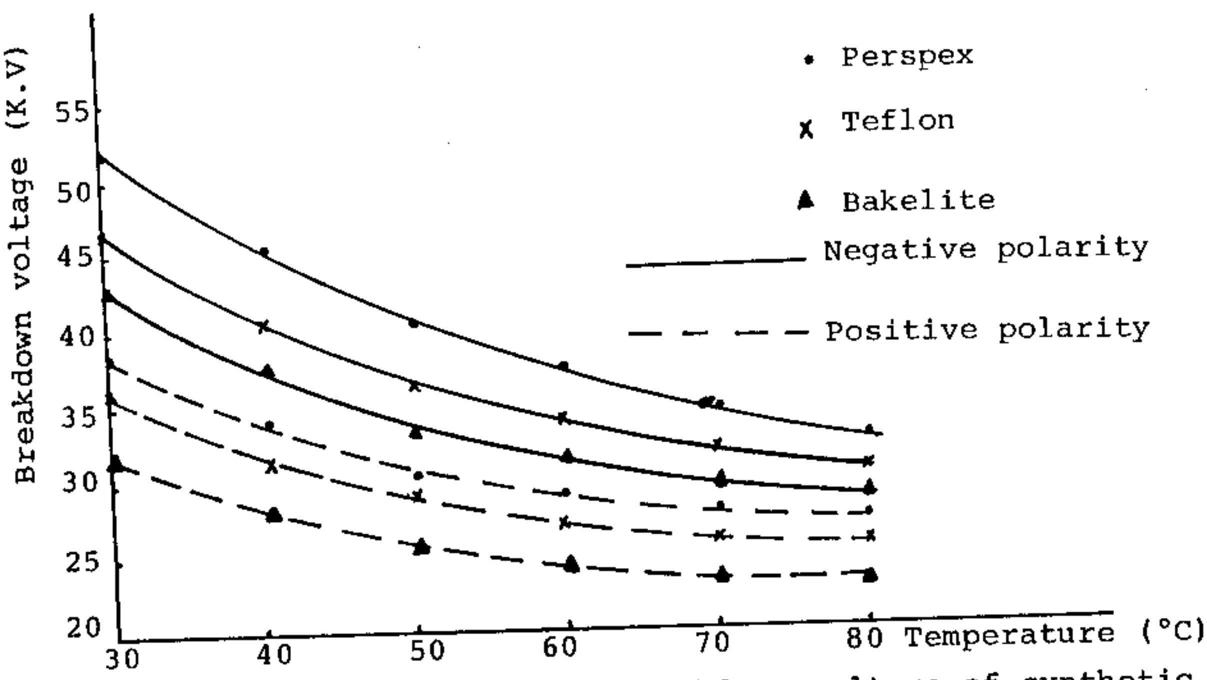


Fig.2. The relation between the breakdown voltage of synthetic materials and the ambient temperature under A.C. voltage.



... (3) The relation between the breakdown voltage of synthetic

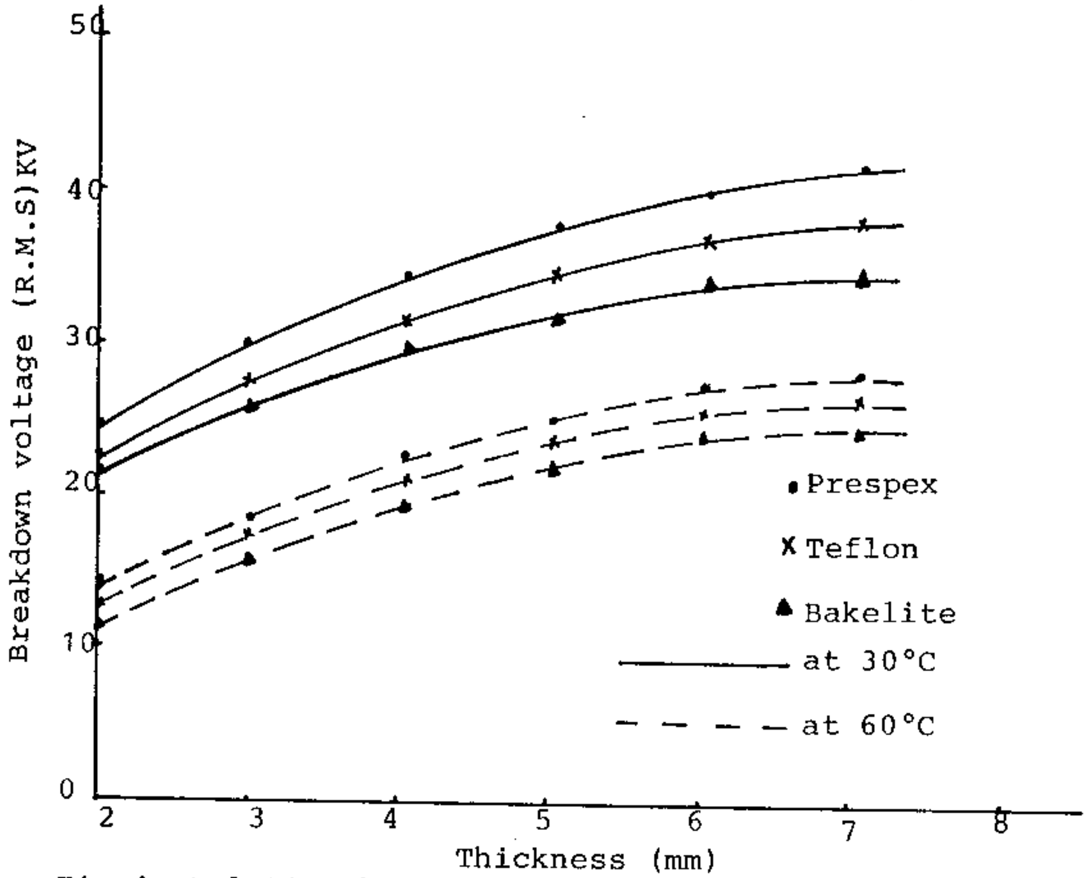


Fig.4. Relation between breakdown voltage and the material thickness under A.C. voltage and electrode diameter of 5 mm.

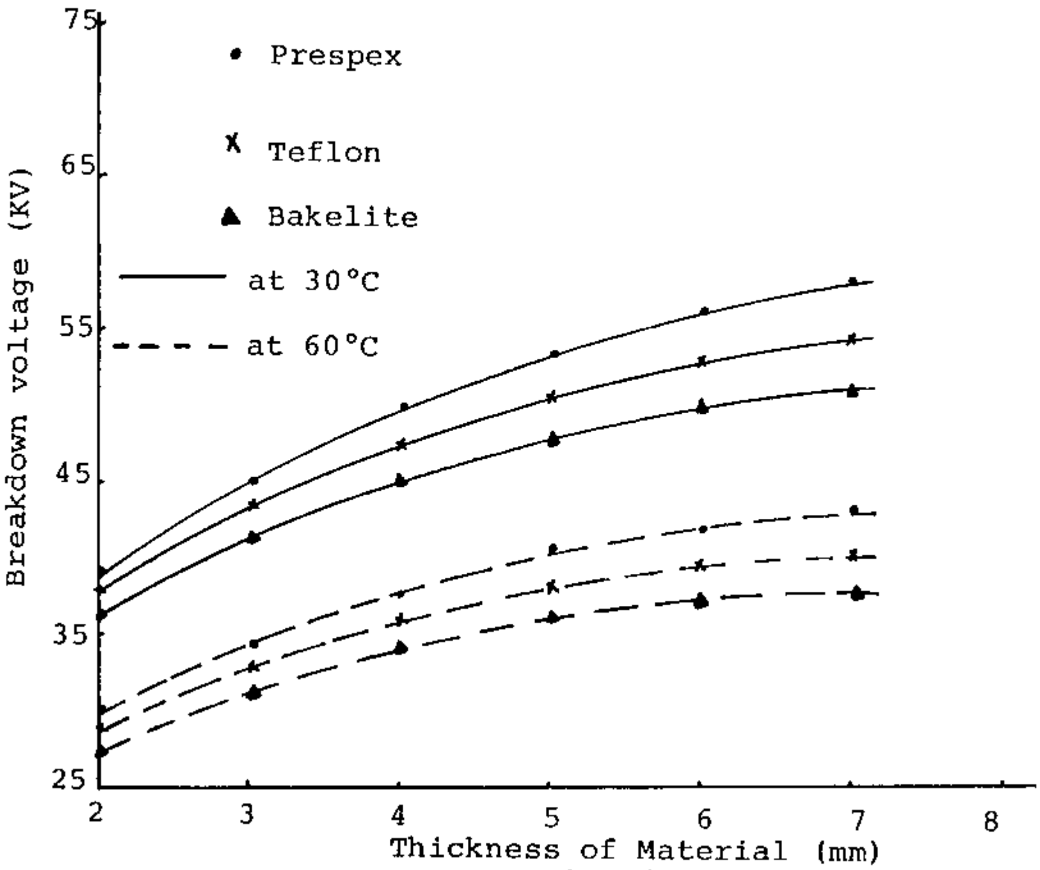


Fig. (5-a)

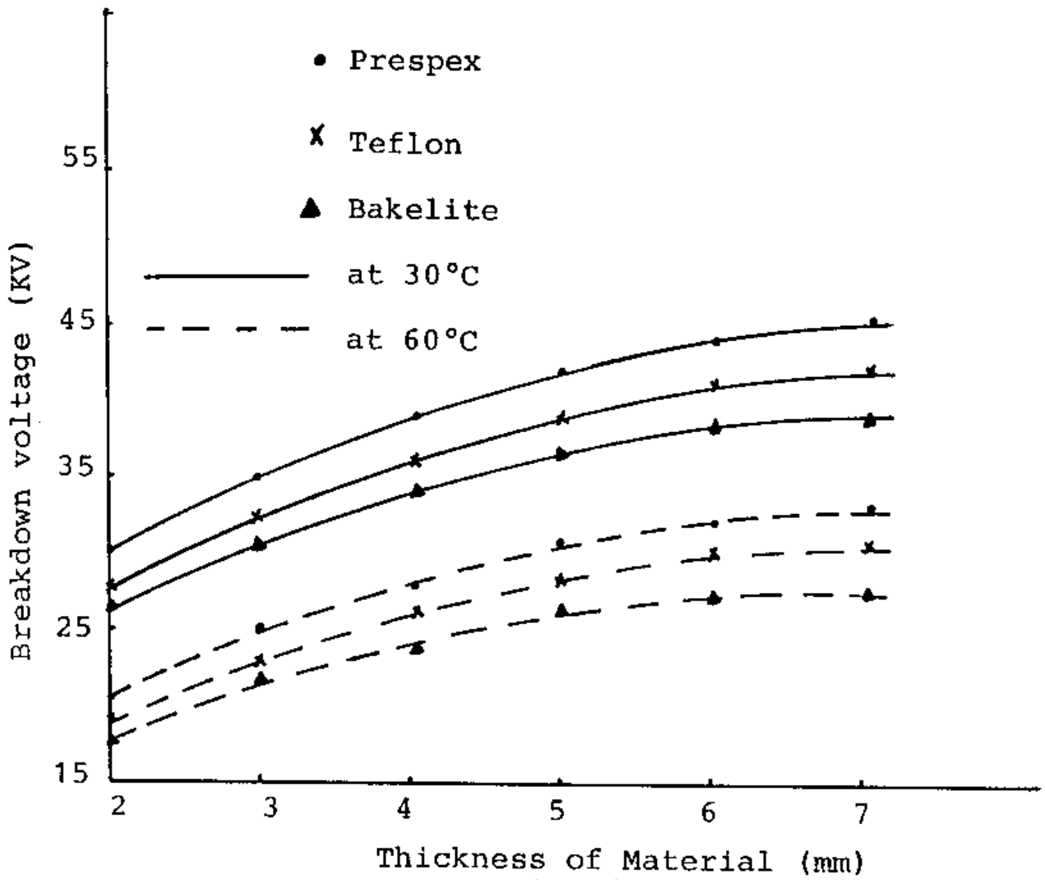


Fig. (5-b)

Fig. (5) Relation between breakdown voltage and the material thickness under D.C. voltage of negative polarity Fig. (4-a) and of positive polarity Fig. (4-b)

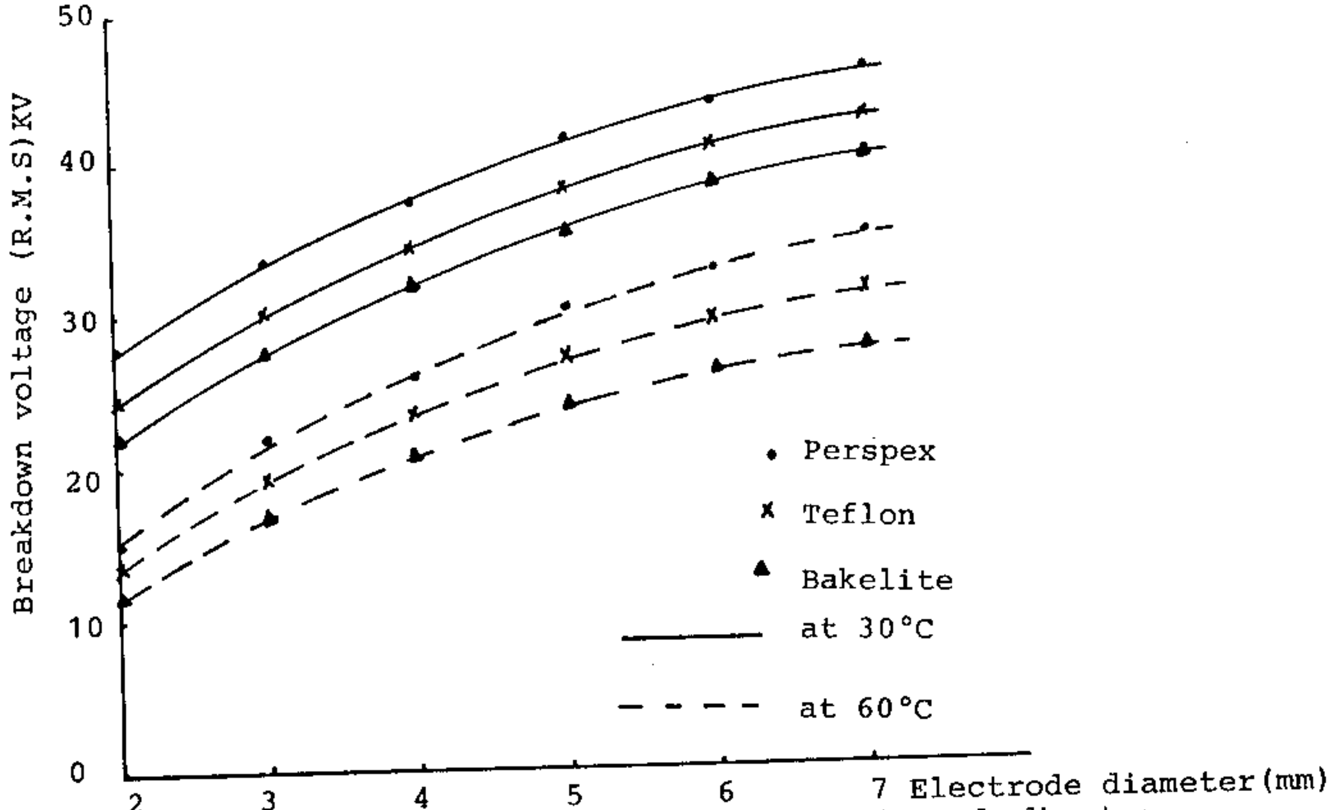


Fig. 6. The relation between breakdown voltage and the electrode diameter under A.C. voltage using samples each of 4 mm thickness.

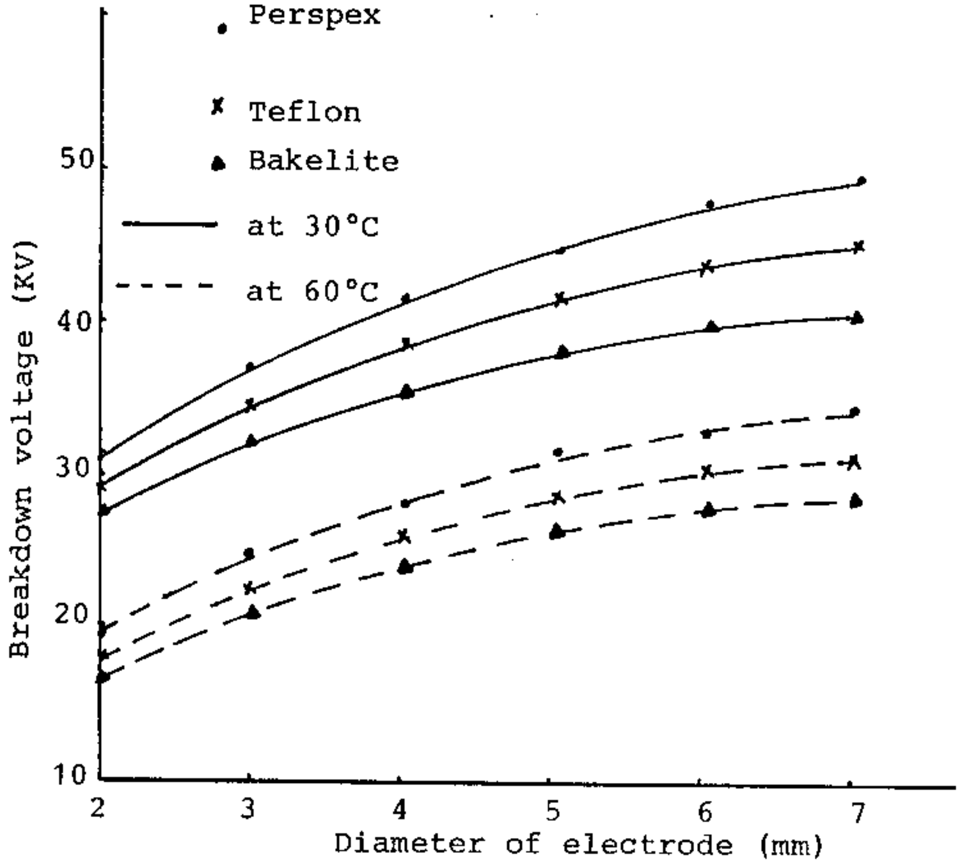


Fig. (7-a)

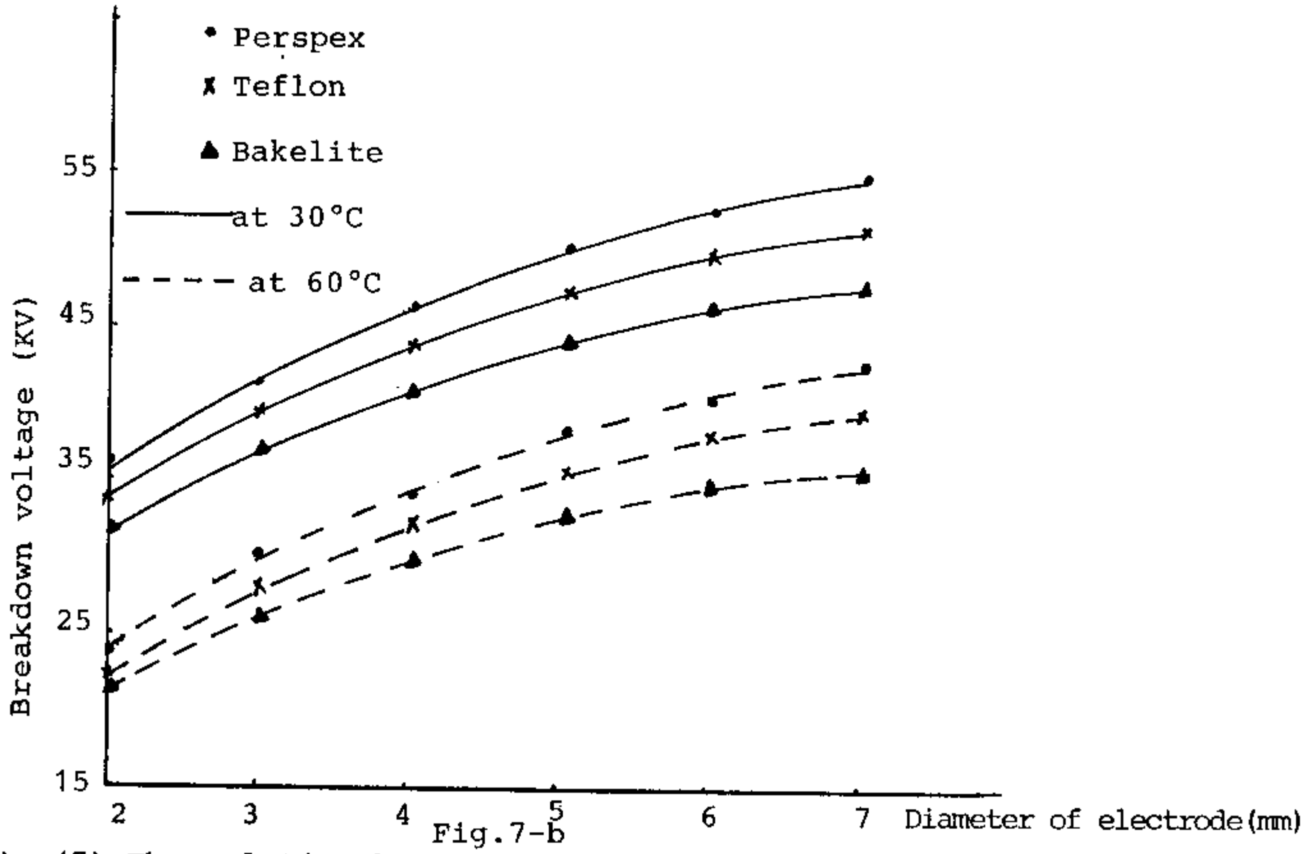


Fig.7-b

Fig.(7) The relation between the breakdown voltage and the electrode diameter under D.C. voltage for samples each of 4 mm thickness
(7-a) under D.C. voltage of positive polarity
(7-b) under D.C. of negative polarity.