INSULATING LIQUID BREAKDOWN UNDER AGITATED CONDITIONS

A

THESIS

SUBMITTED TO

THE DEPARTMENT OF ELECTRICAL ENGINEERING

EAST PAKISTAN UNIVERSITY OF ENGINEERING & TECHNOLOGY, DACCA,

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE (ENGINEERING) IN ELECTRICAL ENGINEERING

By

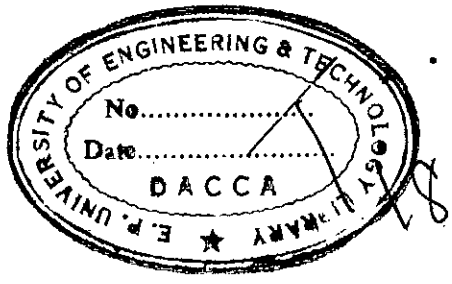
Sheikh Rezaul Karim

DEPARTMENT OF ELECTRICAL ENGINEERING,

EAST PAKISTAN UNIVERSITY OF ENGINEERING & TECHNOLOGY

DACCA.

1966



ACCEPTED AS SATISFACTORY FOR PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF M.Sc.(ENGINEERING) IN ELECTRICAL ENGINEERING (1966)

Examiners (i) 26/12/66

(ii) 26/12/66

(iii) 26/12/66

CERTIFICATE

THIS IS TO CERTIFY THAT THIS WORK WAS DONE BY ME AND IT HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA OR FOR PUBLICATION.

Countersigned

(Superviser)

(Signature of the Candidate.

ACKNOWLEDGEMENTS

THE author wishes to express his gratitude to Dr. A. M. Zahoorul Huq, who supervised this work, for his constant interest, inspiration and advice. The author also wishes to express his thanks to Dr. M. N. Azam, Head of the Department of Electrical Engineering, for his useful suggestions.

The author is thankful to Dr. Hebab Uddin and Mr. K. C. Nath of the Chemical Engineering Department for helping him in working with the viscosimeter.

Special thanks of the author are due to Mr. Ganesh Chandra Das, Mr. Fazle-Rahman and Mr. Ramesh Roy, Post-Graduate students of the Department, for their ready help and co-operation in different stages of the work.

To his unlce, Mr. S. M. Yahya, the author wishes to record his heart-felt gratitude for making arrangement for the typing of these pages. The author also takes this opportunity for thanking Mr. S. A. Sobhan of Elect. Engg. Dept. and Mr. Fazle Elahi of Civil Engg. Deptt., for helping in taking the photographs.

Finally the author acknowledges the grant of a fellowshi from the Directorate of Technical Education, Govt. of East Pakistan, which made this work possible.

CONTENTS

LIST OF FIGURES.

LIST OF TABLES.

ABSTRACT OF THE THESIS

A statistical study of the electrical breakdown of indigeneous oils under different conditions of agitation has been made in this work. For the purpose of agitation a convenient form of electrode configuaration was used. The performances of organic oils such as Castor and Soyabean, were compared with those of commercially available transformer oil.

The dielectric strengths of the oils were investigated keeping the oil, first static, then under agitation. The effect of temperature as well as different degrees of filtration on its breakdown strength was investigated. The breakdown characteristics were studied when temperature and degree of agitation were changed. And finally specific gravity and viscosity of the oils were measured with temperature variation.

The results of the investigation showed that the breakdown voltage of the oils decreased with the increasing speed of agitation. The breakdown strength inweased with rising temperature of the Liquids. But when the oil was again agitated the breakdown voltage fell. The viscosity and specific gravity of the oils decreased with the increasing temperature.

1. INTRODUCTION

The breakdown voltages of the locally available oils were found out previously in this Laboratory with the usual type of the eletrode configuration. The mean ~~xx~~ squared values of the conduction currect fluctuations in these oils were also measured by the custornary noise measurement methods. The effect of localised heat in these oils on the conduction current pulses were also studied.(12)

But the present work is different from the previous ones. The main object of the present investigation was to find out the characteristics of the breakdown voltages when the oils were kept in motion. For conveniently agitating the oils the electrodes had to be made different from those of the customary ones.

The author is not aware of any other work of this kind, where the insulating oil has been mechanically agitated. Some work of this nature was done in the Imperial College, London. But the study was on the Lubricating oils. MacConochie and Cameron(17) of the Mechanical Engineering Department of the same college worked out a novel method of measuring oil-film thickness in Gear Teeth. One of the major troubles in gears is the difficulty in reaching near the line of contact and the consequent problem of making any measurements there. Mac Conochie and Cameron measured gear gaps by electrically breaking down the Lubricant between the running gears. The voltage drop across thin oil films where a constant current was passed, the discharge voltage was found to measure oil-film thickness between loaded gear teeth while running. Similarly, M.Ibrahim (13) worked in the Imperial College Laboratory on 'Discharge Phenomenon as a tool in the Dynamic measurement of thickness of thin oil films between heavily

loaded Machine elements'. All these works are in the realm of Mechanical Engineering.

The object of the work was:-

(i) to investigate the change, if any, in the dielectric strenghth of an insulating liquid, in situations where the insulated parts might be in relative motion with respect to each other. The results would be of general significance in high voltage machine parts under rotation or vibration etc. It was considered that results of this type would be of some practical use.

(ii) to investigate from a more fundamental angle than above, the effect of the dissolved gases on the breakdown strength of the insulating liquids. It was postulated that continuous agitation of the liquid would tend to dislodge the dissolved or suspended gas molecules to some extent and their effect might be predominant on the dielectric strength in such a situation.

2. REVIEW OF BREAKDOWN THEORIES OF OILS

In this section various theories and their salient feature in explaining the breakdown mechanisms in oil will be reviewd in brief. The salient features of the major breakdown theories of oils are as follows:-

When potential is applied on oils dissociation takes place promoting ionization. The magnitude of applied voltage for the purpose may have to be large because of the complex nature of the molecules of the oil. At a certain applied voltage some dissociation of the oil into gaseous substances occur and a discharge may be expected. The presence of air bubbles in the oil further increases the probability of a discharge in the oil. Again, when the oil becomes conductive, the passage of an electric current should always be associated with definite chemical changes. The substance of oil is decomposed at the surfaces of the electrodes where contact is made. Such decomposition must be expected to be promoted by the presence of dirt particles, metallic and carbonaceous in nature. It has been found that filtering out of foreign particles tended to increase the breakdown voltage of oils.

But the breakdown mechanisms of oil are not so simply comprehended. Therefore, constant work and investigation is going on in this field. The electric strength of pure hydrocarbon liquids [8] [25] has been investigated very extensively with a view to understanding the possible mechanisms that ultimately lead to the breakdown.

Sletten, Swan and Lewis [22] observed that the breakdown strength of highly purified n-hexane can be substantially increased when minute quantities of oxygen are dissolved. The possible role of oxygen is that

the oxygen can capture high velocity electons and, that oxygen combine with hydrogen to yeild water vapour. Swan [14] has found that it is necessary to postulate the formation of a bubble due to the vaporization of the liquid at a cathode spot as a possible explanation of the final breakdown.

Clark, [1,2] Khambanonda, [15] Dervenize and Tropper [5] observed the effect of dissolved gases on the breakdown strength of transformer oil. Watson and Higham [27] suggested a breakdown mechanism initiated by cavitation. They listed the possible causes of cavitation as follows :-

(i) dissolved gases coming out of the solution and

(ii) local evaporation of the liquid. El-dine and Tropper [6] noticed the pressure dependence of the breakdown voltages of transformer oil. This led them to believe that the breakdown was essential in the gaseous phase. Gosling [7] found the effect of oxygen, nitrogen and air in transformer oil. And based on these observations he suggested the following model for the mechanism of breakdown : (i) a preparatory stage, when the oscillation of impurity particles in the gap might produce occasional bridges and consequent breakdowns at low stresses; (ii) the subsequent steady state condition in which both the anode and cathode space charges are involved, the two space charges being, in fact, interdependent. At this stage the conduction current is provided by the ejection of electrons from the cathode into the liquid; (iii) the final stage which depends on the ability of the liquid to absorb energy of the elctrons without dissociation, and its tendency to combine with the hydrogen atoms liberated under the electrical stress. These two properties of the constituents of the insulating liquid ultimately decided if an initiating event at the cathode will be quenched or will continue, finally leading to the breakdown in the

gaseous phase. It can be noted here that this explanation is like the Townsend gaseous discharge.[19] Gosling[7] also investigated the important constituents of transformer oil in the characteristic of its dielectric strength. Accordingto his suggestions and findings electrical strength is raised in unsaturated hydrocarbons because of its ability to trap electrons which dissociates the liquids into gases.

But KOK [16] suggested that the conductivity of liquid insulators is mainly due to ions whereas breakdown should be ascribed to 'coarser particles'. KOK considered oils of commercial standards of purity. He was aware of the beneficial effect of certain additives in the liquid, such as aromatic compounds. But he considered that the inhibiting action was due to aromatic covers around the impurities, which prevented flocculation and formation of bridges leading to breakdown.

L. Angerer[21] from his experimental work reported the effect of additives known as hydrogen acceptors on the breakdown strenght of transformer oil and finally he proposed the following three phases of breakdown in liquids: (1) The initial phase during which the formation of microscopic cavities due to thermal fluctuations is enhanced by the presence of electric field and mechanical effects caused by the field. (2) The second phase, during which the electrons moving through the liquid permeated by microcavities can gain enough energy to bring about dissociation accompanied by gas evolution, so that micro bubbles can form. This phase may be regarded initiating or triggering the final breakdown. (3) The gaseous breakdown, which takes place when the rate of bubble formation exceeds the rate at which the evolved gas can be absorbed by the liquid.

The breakdown theories would be incomplete without mentioning conduction current in insulating liquid under electrical stress. In view of the fact that the study of the electrical strength of liquids has always involved considerations regarding the movement of electrons, ions and charged particles in the gap, conduction current measurements under varying conditions have formed a major part of these investigations. On a more practical level, conduction current measurements have served as a check on the reliability and repeatability of results; as a control of experimental conditions, such as the degree of purity or the state of ionization of the liquids. More important than that, such measurements, especially just prior to breakdown, have been assumed to contain important clues to the actual breakdown mechanism.

Huq and Tropper [11] investigated the conduction current pulses in organic liquids and measured the mean square values of conduction current fluctuations. They studied the effect of dissolved gases such as air, oxygen and nitrogen as well as that of anthraquinone which is known to have an important effect on the gassing properties of transformer oil. Their findings are in consonance with the Gosling's [7] model of breakdown. Their explanation is as follows.

It is postulated that electrons are emitted from the cathode. These electrons are accelerated in the barrier and space charge layer adjacent to the electrode and thus ejected into the liquid where they are further aculerated by the applied field. When such an electron collides with a molecule of the liquid, ionization or dissociation may take place. Since the dissociation energy of the carbon-hydrgen bond is 3.78 ev and the ionization energy about 10 ev, it is more likely that dissociation will occur when electrons of sufficient energy emerge from the cathode region.

T18

From the observed fluorescence in oil when subjected to high stress, it follows that such high energy electrons are present in the liquid, and moreover, it is known from gassing tests that dissociation certainly takes place when the oil is bombarded by high energy electrons.

The dissociation products, such as hydrogen will tend to form bubbles and in this process the affinity of oil for hydrgen as well as its electron trapping properties will become important. In this respect the unsaturated hydrocarbons would be advantageous and quenching of such initiating events would probably take place. The conditions for the paraffins would be less favourable, for electron trapping is unlikely and little hydrogen would be absorbed. With increasing fields this process would continue until the gas evolution is greater than the ability of the surrounding liquid to absorb it. A bubble will then form and the acceleration of the electrons within the bubble will lead to further dissociation so that the bubble may rapidly grow. Additional positive and negative ions will be formed in this region, enhancing the space charges at both electrodes, which in turn will introduce a greater number of electrons and positive ions. This process is of an unstable nature and complete breakdown of the liquid may ensue. However, if the test liquid contains a gas in solution, it is quite possible that the dissolved gas molecules become detached by impact with high energy electrons and this may also lead to nucleation and bubble formation. This phenomena is of erratic nature and they constitute the 'noise' in the external circuit, i.e. current fluctuations and pulses which are superimposed on the steady conduction current. It is reasonable to suppose that the likelihood of breakdown taking place will depend on the occurrence of high amplitude pulses and that any measure that brings about a reduction of these amplitudes will be beneficial as far as the electric strength values are concerned.

The present work was undertaken to investigate the effect of continuous agitation of different degrees on the breakdown strength. Since in the breakdown process, the dissolved gas molecules play a decisive role, it was considered that continuous agitation (due to friction of a rotating cylinder) in a film of liquid will tend to dislodge the dissolved and/or suspended gas molecules to some extent, and this fact will have significant effect on the breakdown voltage. In such a situation, the viscosity of the liquid,--and the effect of temperature on viscosity as well as on the quantity of gas in solution or suspension, would have considerable importance.

3. EXPERIMENTAL APPARATUS AND METHODS

3.1 INTRODUCTION

The breakdown strengths of insulating oils under agitation, as far as the author is aware, is being investigated for the first time in liquid dielectrics research. One of the aims of this investigation was to collect data regarding some indigenous oils. The most widely used transformer oil has also been investigated under identical conditions for the purpose of comparison. Of the numerous locally available oils, Soyabean and Castor Oil were choosen because their breakdown strength were found to be the highest under the usual spherical electrode configuration and static conditions of the oils, by previous works[12] carried out in this Laboratory. For the purpose of agitation a convenient form of electrodes were made. In this work the following course of investigations was followed

(I) The breakdown strenght of oils were determined from stationary condition to successively increasing speed of agitations.

(II) The effect of rising temperatures on oils were investigated.

(III) The effect of rising temperature and rising speed of agitation were simultaneously studied.

And (IV) the viscosity of the oils with temperature variation was determined by a falling ball viscosimeter.

Besides these the successive breaks of oils were noted. The scatter of the breakdowns under agitation was determined and also effect of impurities on the dielectric strengths was found by using different grades of sintered glass filters.

3.2 THE TEST CELL AND ELECTRODES: The cell in which oil was taken itself played the part of one of the electrodes. The cell was cylindrical in shape and made of mild steel. The dimensions of this cylindrical electrode is shown in Fig.2. The other electrode was also made of mild steel but it was a solid cylinder which could be placed in side the other electrode. Different sizes of this solid cylinder was made to get different uniform gap settings between the electrodes. The hollow cylinder which would contain oil formed the high potential stationary electrode. Its closed end was conveniently machined to secure the high tension terminal of the high voltage D.C. generator. The other solid electrode formed the electrode at the earth potential. This electrode was r-otated inside the hollow cylindrical space of the other electrode to agitate the oil taken inside it.

The rotation of this solid electrode was done by means of a fractional horse power Universal motor. The holding end of this electrode was threaded so as to fit in the coupling end of the motor. In arriving at the present dimensions of the electrodes a wooden model was first made and studied.

For different gap setting the diameter 'D' and length 'L' of the solid electrode were made different. But the hollow cylindrical electrode was of the same dimension for all gaps. The gaps were taken in milli-meter(mm). For each gap in mm the following values of L and D were used.

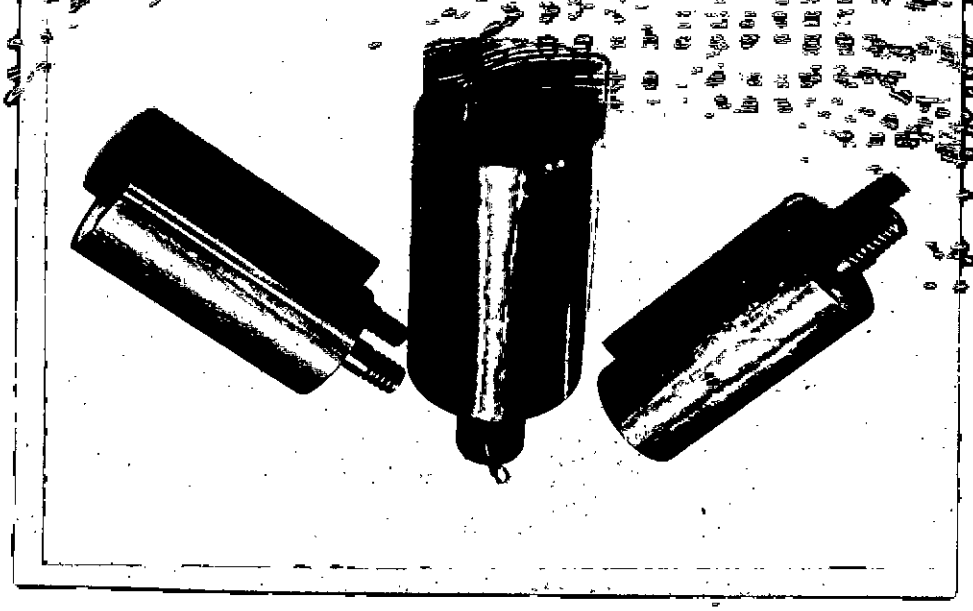


FIG.I PHOTO OF ELECTRODES.

TABLE-I
DIMENSIONS OF ELECTRODES AND GAP SETTINGS

Gap (mm)	L (inch)	D (inch)	Exact gap $=\frac{1.25-D}{2}=2-L$ (inch)
1	1.961	1.172	.039
2	1.922	1.094	.078
3	1.883	1.016	.117
4	1.844	0.938	.156
5	1.805	0.860	.195

3.3 METHOD OF AGITATION: The agitation of the oil was done by means of a fractional horse power motor. The threaded end of the solid sphrical electrode was serewed into the coupling system of the motor. The coupling was specially made to protect the motor from the high village side of the generator as well as to hold the electrode securely. The cross-section view of this coupling system is shown in fig. 2. The motor was mounted vertically. The high tension lead of the high voltage generator was fitted to the hollow electrode which contained the test liquid. The other electrode, which would be rotating with the rotor of the motor, was earthed by a thin mild steel disc connected with the motor coupling in conjunction with an improvised steel brush connected to the earth terminal of the generator system. This whole system has been shown in fig. 2 and fig. 3.

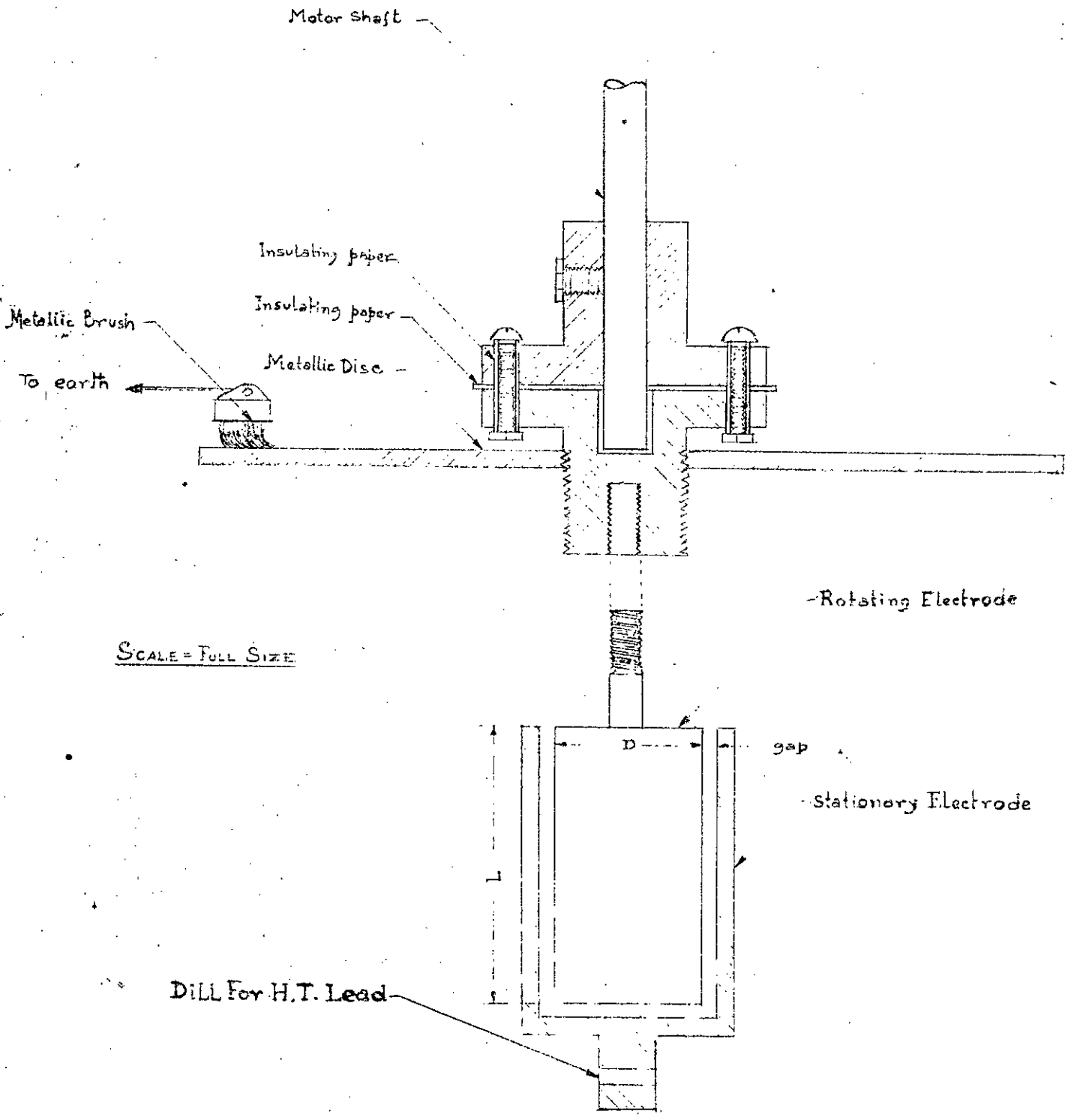


FIG. 2 A CROSS SECTION VIEW
OF ELECTRODES & COUPLING SYSTEM

FIG.3-PHOTO OF COUPLING & MOTOR

(Fig. 2 and 3)

The speed of the motor was determined by the voltage across its terminals. It was found that regulation and speed control of the motor was better with d.c. supply. It was, therefore, used as a d.c. motor, the speed of which was varied by varying the applied voltage by means of a potentiometer. A curve relating the supply voltage with speed was determined. The speed was determined by means of a Techometer and varified by a stroboscope. The voltage/speed characteristic of the motor is given in fig.10. This curve was used in determining speed of the motor from its applied voltage.

TABLE - II

VOLTAGE VS SPEED OF D.C.MOTOR

Voltage (Volts)	Speed (Rpm)
7	140
9	288
10	380
11	480
12	608
14	748
18	1000
20	1432
23	1492
26	1708
29	1800
32	1856

3.4 THE HIGH VOLTAGE SOURCE: The voltage source was the/ Spellman Model Lab-6 High-Voltage Power Supply (0 to 60 KV). This high voltage Power Supply was designed for use with high input impedance equipment requiring a high voltage input from zero to 60 KV d.c. It can supply load current upto 1 milli-ampere. Its own supply is 117 volts a.c.

The unit is constructed with three primary assemblies: the front panel assembly, the chassis assembly and the high voltage assembly.

Front Panel Assembly: It contains the energizing and operating controls plus the output voltmeter. Convenient ground cable connection was provided by external ground terminal which was fastened to the front panel ground terminal. The high-voltage cable, which is connected directly to the output of the high-voltage rectifier circuit, passes through and is mechanically fastened to the front panel, thus allowing convenient handling of this cable without the danger of lossening or short circuiting the internal high voltage electrical connections.

Chassis Assembly: The chassis assembly contains the low voltage circuits of the high voltage power supply. These circuits include the local oscillator, the buffer amplifier, the power amplifier, the filament supply, the regulating circuit, the plate, filament and bias voltage supplies.

High - Voltage Assembly: The high voltage assembly includes the plastic housing and all the electronic components contained within and attached to the housing. These components include the 35-KV high-voltage step up coil, the high voltage doubler circuits, the high-voltage rectifier circuit and the filament supply circuit. The electronic components of the high voltage assembly are

mounted with high - dielectric insulators and interconnected with spherical terminals and corona rings to obtain stability of operation with compact packaging.

3.5 CLEANING PROCESS: Before oil was taken for a test, the electrodes were cleaned so as to free it from extraneous oily substances on dust particles.

The metallic electrode picus were first boiled in soap solution for about five minute. Then they were washed in hot water. After this they were rinsed in pure benzene ($C_6 H_6$). In the absence of benzene Carbon tetrachloride (Ccl_4) was sometimes used. Finally the electrode pieces were dried by blowing hot air from a blower. Benzene Vapour being poisonous care was taken so that it was not inhaled.

3.6 FILTERING OF OILS: In order to see the effect of the suspended impurities on the breakdown strengths of oils, the oils were filtered by different grades of 65 mm diameter sintered glass filters. The number of the grades and their corresponding porosities of the filters are given below:

TABLE -III
POROSITY OF FILTERS

Grade	Porosity
1	90-100 microns
2	40- 90 microns
3	15- 40 microns
4	4- 15 microns
5	Max^{m}. 1.4 microns, average 1.1 microns

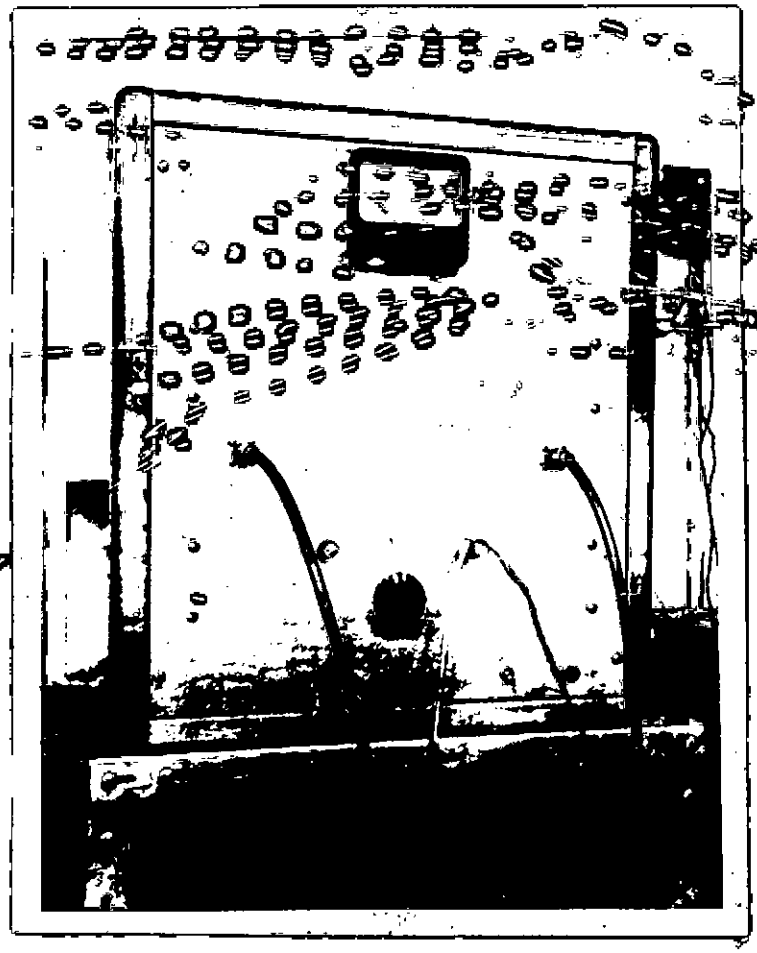


FIG.4-PHOTO OF HIGH VOLTAGE GENERATOR

3.7 VISCONSIMETER: In measuring viscosity of the oils at different temperatures the Haake Falling-Ball-Viscosimeter of German manufacture was used. The viscosity was measured by recording the time that the ball required in falling through a particular distance of a glass tube filled with the oil. The time was recorded by means of a stop watch. The temperature variation of the oil was made by means of a Heating Jacket. The Heating Jacket and the oil pot were concentric glass tubes of which the Heating Jacket was larger, and the oil tube was inside it. The Jacket had an electric heater with thermostatic control. From different ranges of temperatures different liquids are used in the Jacket as stated below:

(i) For temperatures from -60 to 1°c : methanol (Methyl-alcohol)

(ii) for temperatures from +1 to +98°c : distilled water

(iii) for a temperature of +100°c : distilled water - 20% glycerin

(iv) for temperatures from + 100 to 150°c: glycerin of at least 1.26 specific gravity or ethylenglycol.

A cross-section view and a photo of the viscosimeter are shown in fig.5 and fig.6 respectively.

In the present investigation work was done in the temperature range of + 1 to + 98°c. Therefore, only distilled water was used in the Heating Jacket. In determining the viscosity of a oil, the specific gravity of it had also to be determined. The specific gravities of the oils were determined by means of a specific gravity bottle. Finally the absolute viscosity in centipoise was calculated by the following relation $n = F(S_k - S_f)K$

Where n = absolute viscosity in centipoise

F = dropping period of ball in seconds

Sk = Specific gravity of ball

IMPORTANT FEATURE

(4) Thermometer
(11) Falling ball
(A) Upper marking in the oil tube
(3) Lower marking in the oil tube
(R) Heating jacket

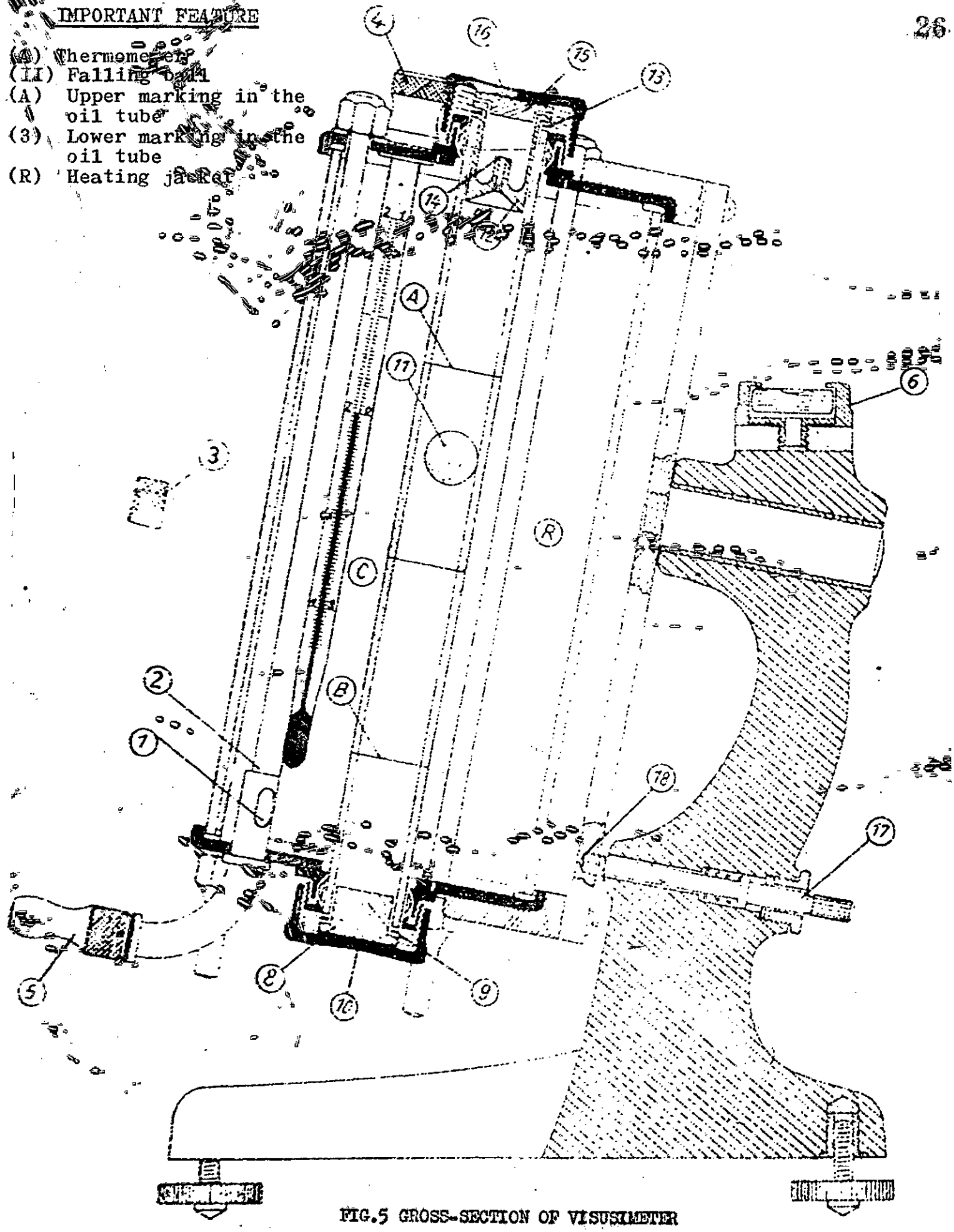


FIG.5 GROSS-SECTION OF VISUSIMETER

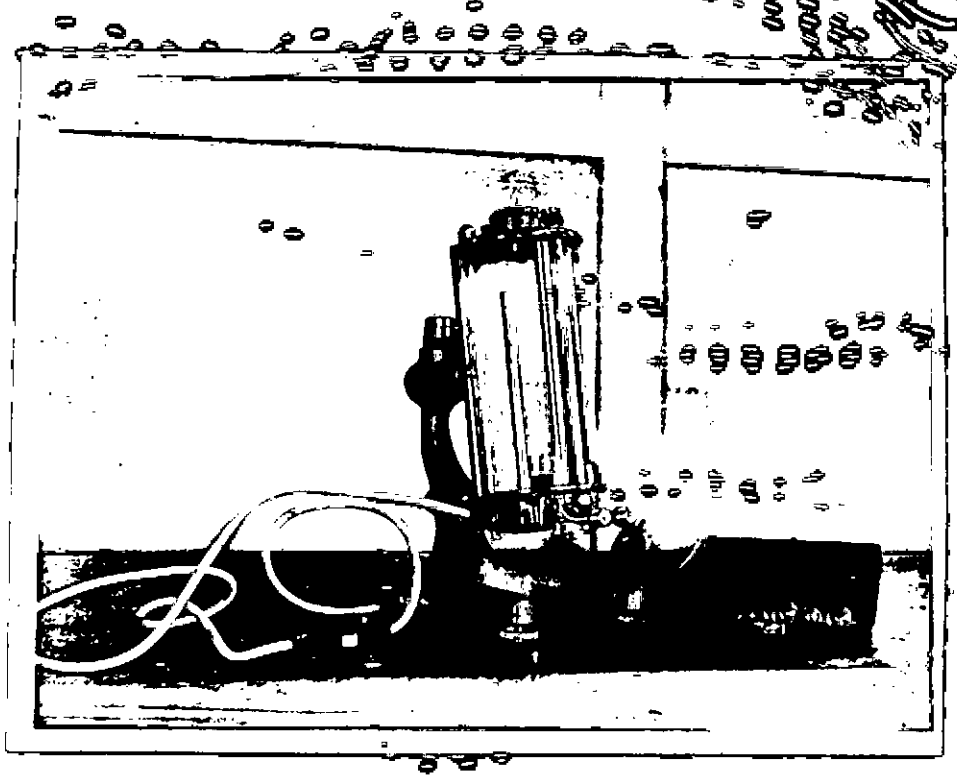


FIG.6—PHOTO OF VISCOSIMETER

S_f = Specific gravity of liquid tested at the measuring temperature

K = ball constant.

A chart of S_k and K of different sizes of balls were given in the operation mannual of the viscosimeter.

3.8 TEMPERATURE VARIATION OF THE TEST LIQUID: When the effect of temperature variation on the dielectric strength of the oils were investigated the outer high potential electrode, which contained the oil, was dipped in an oil-bath which, in turn, was heated by an electric heater. The oil-bath was stirred occassionally to keep the temperature unform. The temperature of the oil under investigation inside the electrode, was assumed to be the some as that of the oil bath. Fig.7 shows a sectional view of this arrangement.

3.9 THE TEST CIRCUIT: Fig.8 shows the complete circuit. All high voltage connections were securely made. The CRO, as well as the sudden breakdown noises were used as indicators of breakdown. All the sharp edges were carefully eleminated to avoid corona loss in the circuit. The high voltage joints were eaxed to suppress corona.

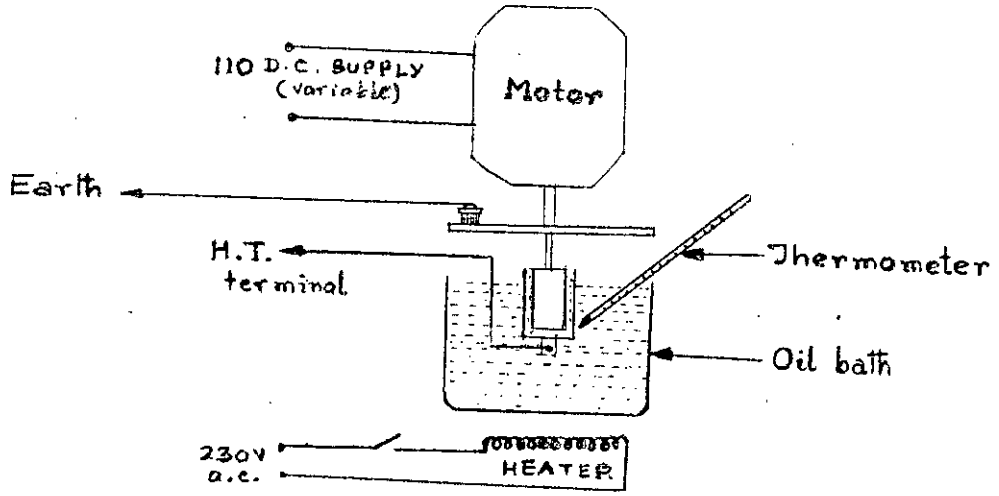


FIG. 7 SKETCH OF HEATING ARRANGEMENT

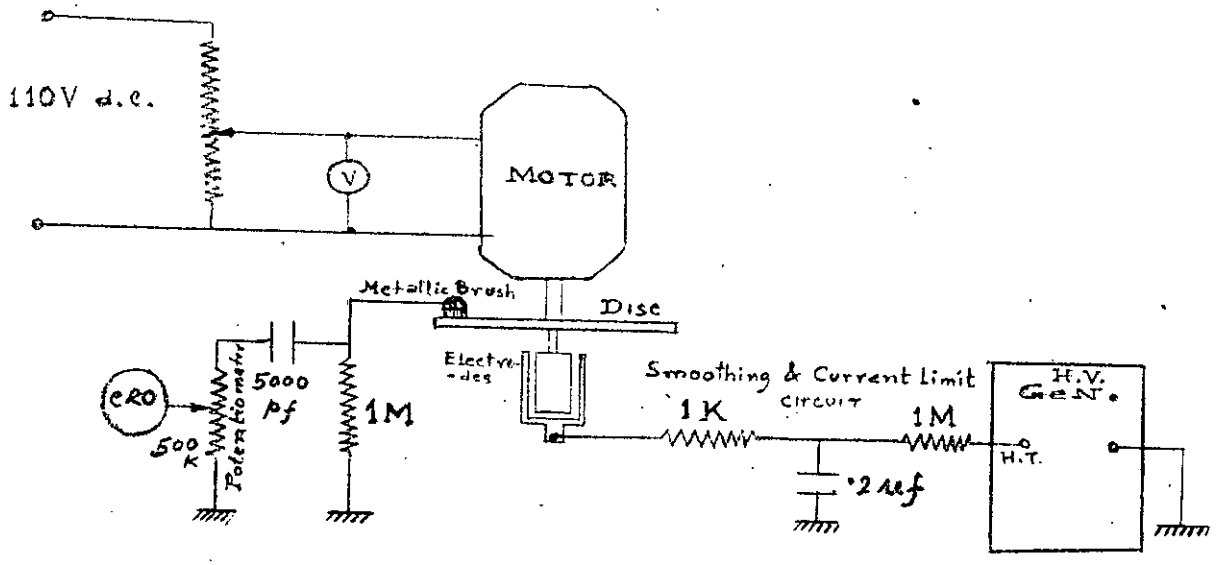


FIG.8-THE COMPLETE TEST CIRCUIT

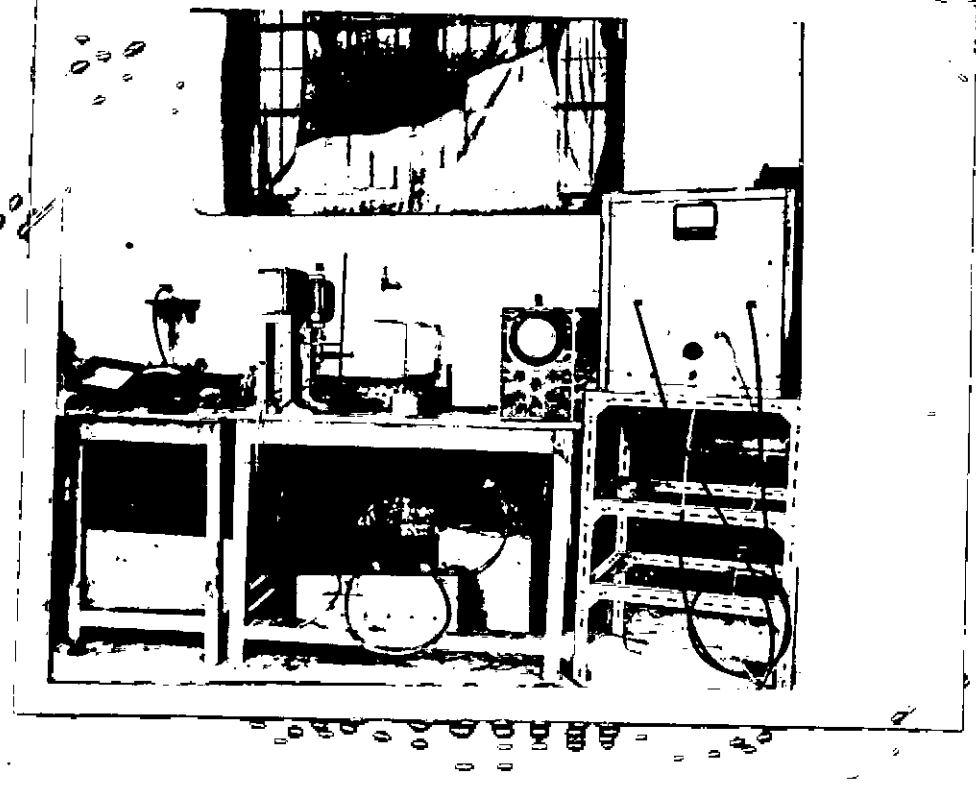


FIG.9. PHOTO OF THE COMPLETE TEST SET-UP.

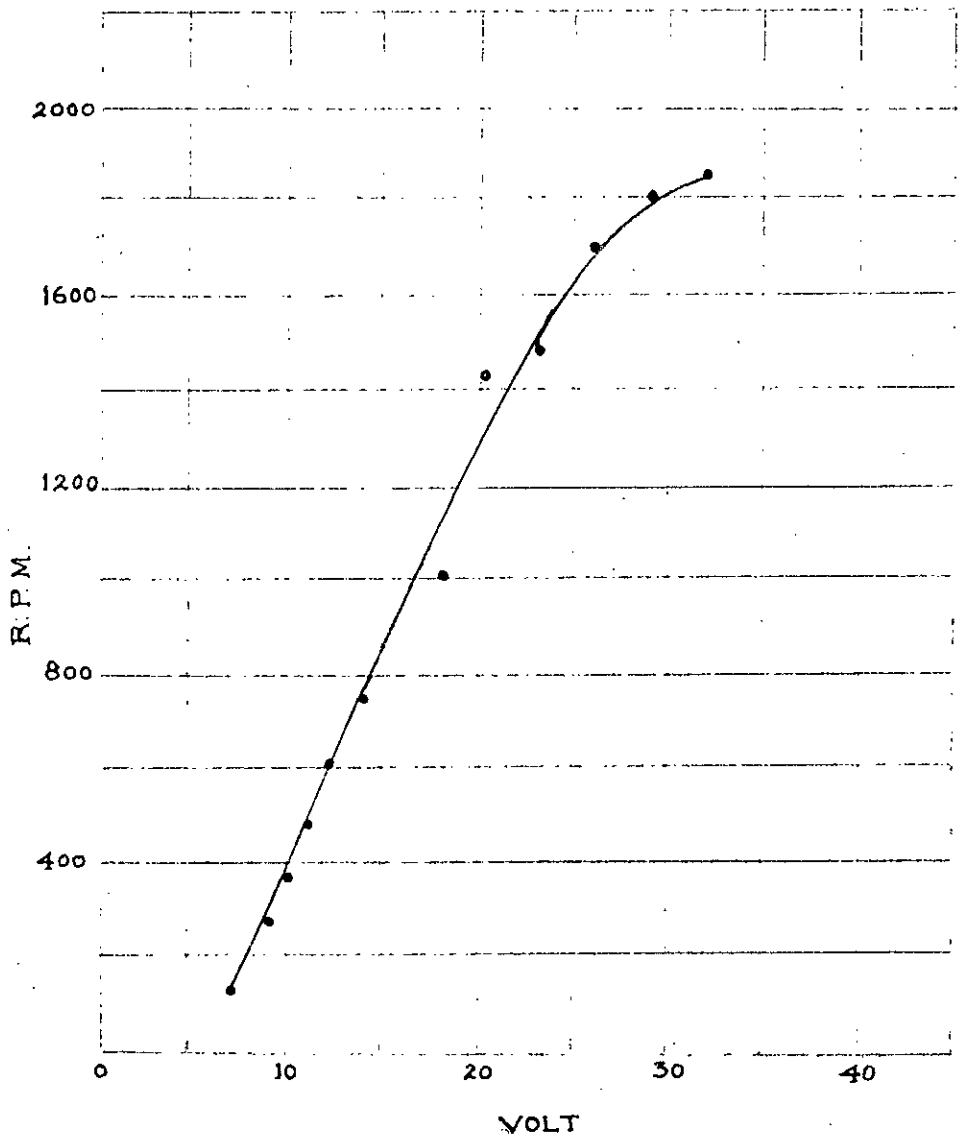


FIG.10 SPEED/VOLT CHARACTERISTIC OF THE MOTOR

4. RESULTS

4.1 GENERAL REMARKS: The experiments with unfiltered oils could not be done after much endeavour because of formations of the bridges inside the electrodes by suspended particles. All data and results are, therefore, on filtered oils. The speed of agitation of the oil by the motor was first denoted by its supply voltage. This voltage was then converted into rpm by referring to the previously given speed/voltage characteristic curve of the motor in Fig.10. The average breakdown voltage given in the data is the arithmetic mean of ten readings, the standard deviation [9,14] of which is also given. The breakdown voltage at higher speed could not be recorded because at higher speeds the oil inside the electrode was thrown out and therefore, the reading would be erroneous.

4.2 Transformer Oil: Filtered, grade IAG, 90-100 microns porosity.

TABLE - IV
SPEED VS BREAKDOWN VOLTAGE OF TRANSFORMER OIL AT DIFFERENT GAPS

Electrode gaps (mm)	Speed of agitation (rpm)	Av. Breakdown voltage (kv)	Standard deviation (σ)
1	0	2.68	0.21
1	480	1.92	0.25
1	760	1.76	0.15
1	1240	1.25	0.20
2	0	2.93	0.16
2	200	2.74	0.03
2	430	1.88	0.04
2	1240	1.69	0.28
2	1680	1.42	0.04

TABLE-IV

Electrode gaps (mm)	Speed of agitation (rpm)	Av.Breakdown voltage (kv)	Standard deviation (σ)
3	0	3.98	0.36
3	480	3.12	0.41
3	600	2.39	0.39
3	880	2.15	0.12
3	1580	2.07	0.22

4.3 SOYABEAN OIL: Filtered, Grade IAG, 90-100 microns porosity.

TABLE V
SPEED VS BREAKDOWN VOLTAGE OF SOYABEAN OIL AT DIFFERENT GAPS.

Electrode gaps (mm)	Speed of agitation (rpm)	Av.Breakdown voltage (kv)	Standard deviation (σ)
1	0	1.45	0.23
1	260	1.29	0.22
1	380	1.15	0.20
1	680	1.85	0.33
2	0	8.80	1.65
2	400	8.70	0.56
2	700	8.25	0.98
2	960	6.20	0.70
3	0	12.14	1.04
3	410	11.28	1.26
3	640	12.00	0.72
3	800	11.42	0.95
3	1200	11.72	1.20

4.4 CASTOR OIL: Filtered, Grade-IAG, 90-100 microns porosity.

TABLE VI
SPEED VS BREAKDOWN VOLTAGE OF CASTOR OIL AT DIFFERENT GAPS

Electrode Gap (mm)	Speed of agitation (rpm)	Av.Breakdown voltage (kv)	Standard deviation ( )
1	0	4.44	0.49
1	360	2.95	0.44
1	620	2.59	0.40
1	880	2.88	0.45
1	1000	2.65	0.39
1	1320	2.60	0.45
2	0	6.50	0.97
2	400	5.51	0.35
2	800	4.03	0.41
2	1040	4.10	0.26
2	1200	5.06	0.32

4.5 EFFECT OF INTERMITTENT AGITATION: In this set of experiments the oil was agitated for about five minutes and then the breakdown strength of the oil was observed after stopping the agitation. The typical curves are given in Fig.14, Fig.15 and Fig.16. A point in the figures denotes a mean of five readings.

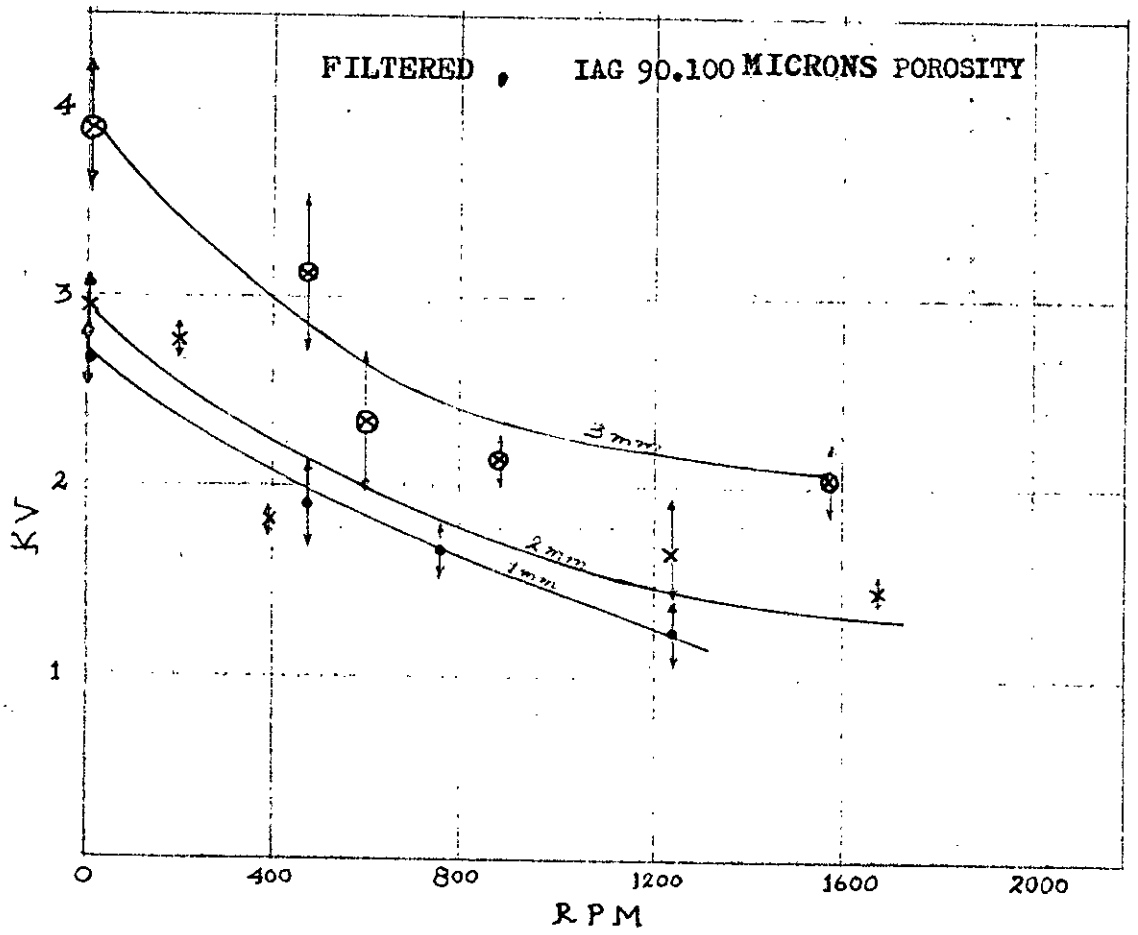


FIG.11 TRANSFORMER OIL SPEED CHARACTERISTIC

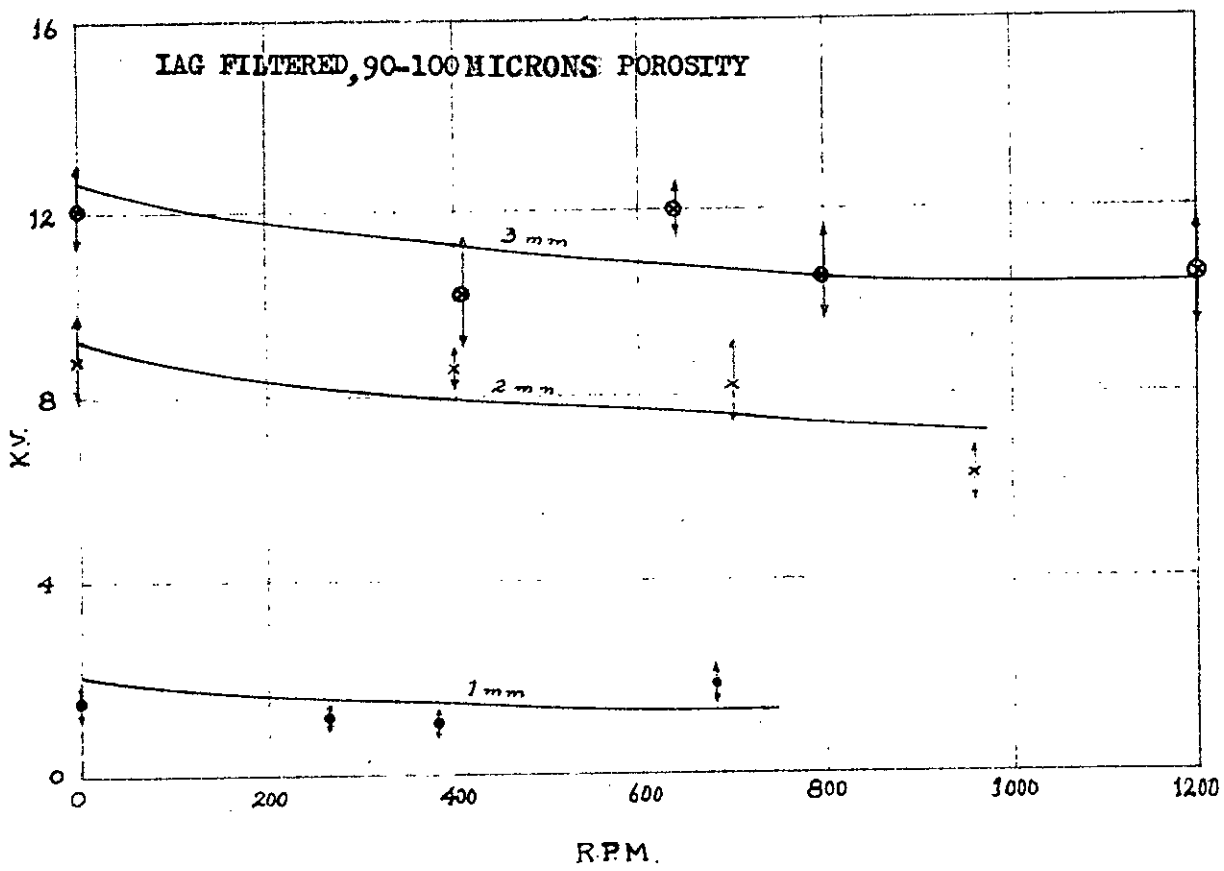


FIG.12 SOYABEAN OIL SPEED CHARACTERISTIC

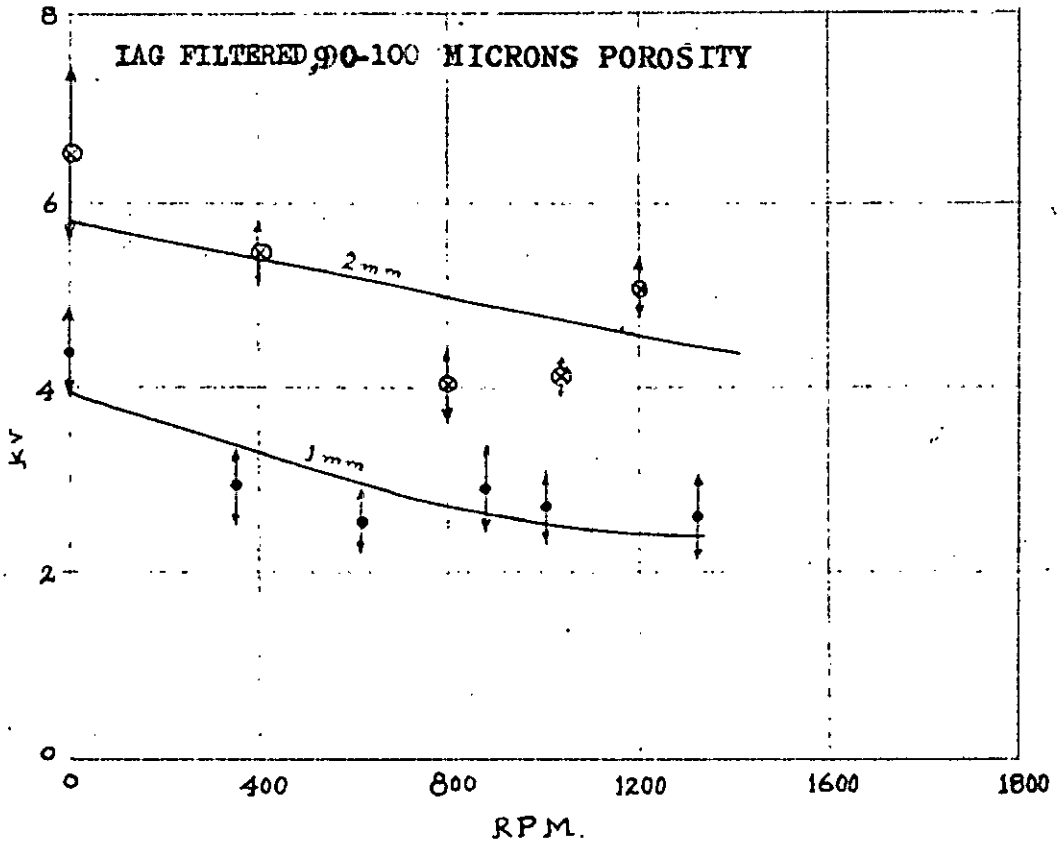


FIG.13 CASTOR OIL SPEED CHARACTERISTIC

TABLE VII

INTERMITTANT AGITATIONS AT DIFFERENT GAPS
(AGITATED FOR 5 MIN. AT 400 RPM)

Oil	Gap (mm)	No. of Breaks	Breakdown voltage (kv)
Trasformer	2	1	5.1
(2 AG fil-	2	2	5.2
tered)	2	3	5.3
"	2	4	5.8
Transformer	1	1	2.33
(1 AG fil-	1	2	2.65
tered)	1	3	4.
"	2	1	2.95
"	2	2	3.75
"	2	3	4.5
"	3	1	3.95
"	3	2	4.25
"	3	3	4.75
Soyabean	1	1	.4
(1 AG fil-	1	2	.6
tered)	1	3	4.8
"	2	1	2.2
"	2	2	5
"	2	3	6.4
"	3	1	12
"	3	2	12.4
"	3	3	14.0

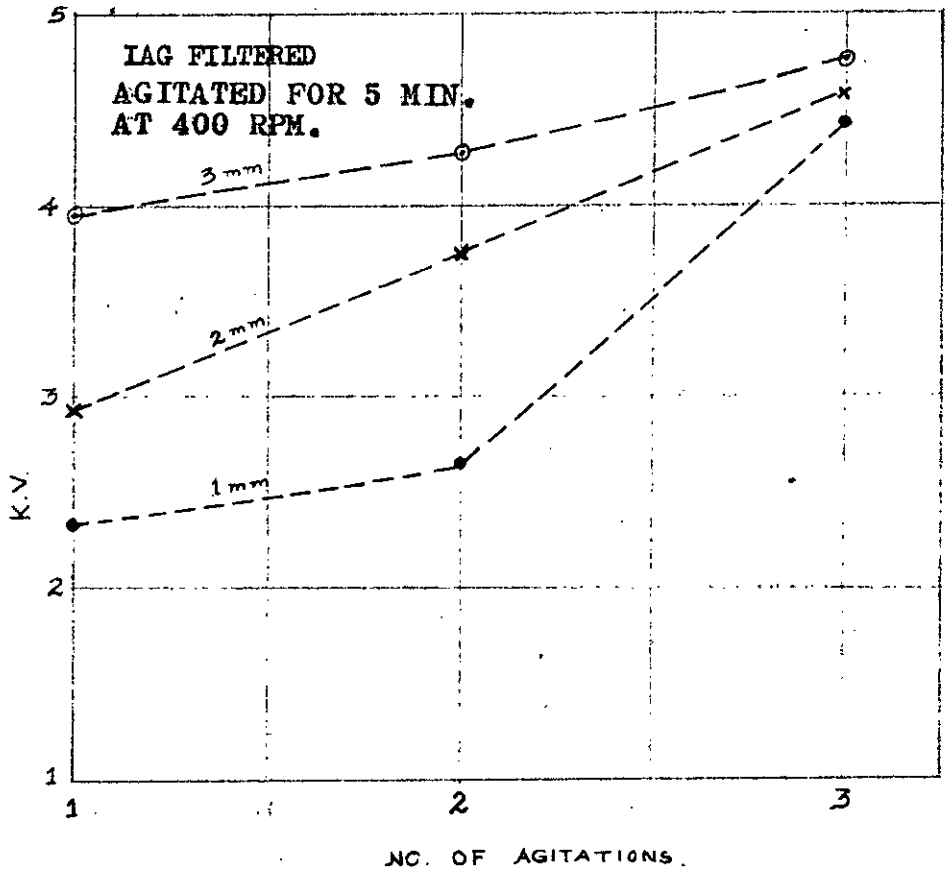


FIG.14 INTERMITTANT AGITATION OF TRANSFORMER OIL

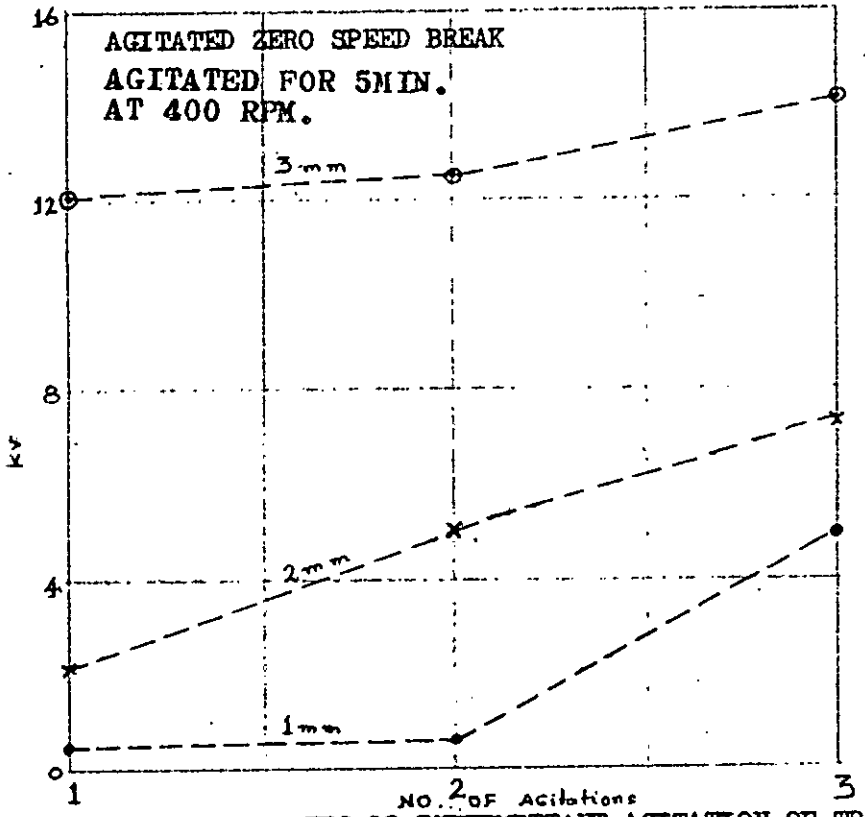


FIG.15 INTERMITTANT AGITATION OF TRANSFORMER OIL

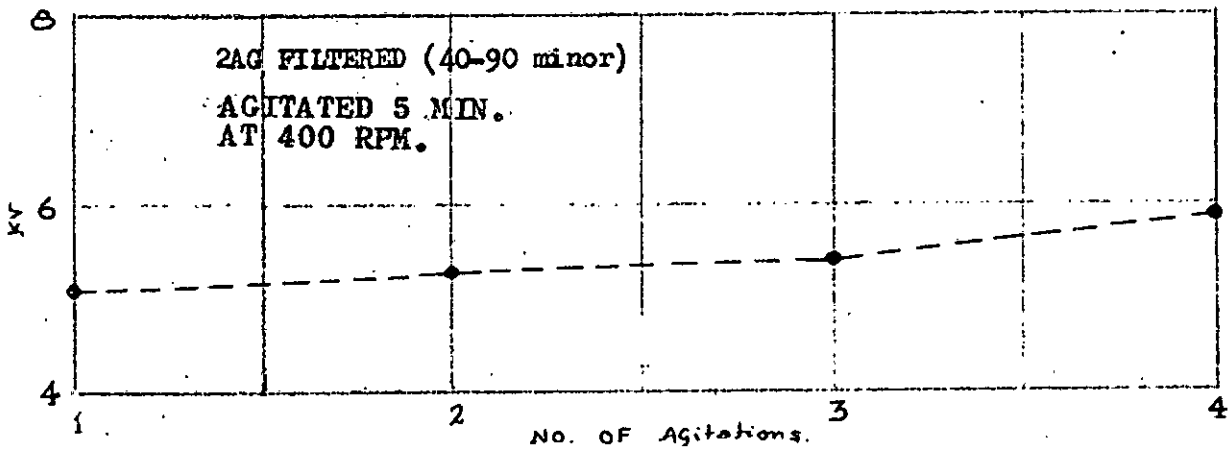


FIG.16 INTERMITTANT AGITATION OF TRANSFORMER OIL

4.6 SUCCESSIVE BREAKS: The trends of successive breaks were studied as shown in Fig.17, Fig.18 and Fig.19. 2 mm gap set and IAG grade filtered of all the three oils were investigated in this experiment.

4.7 TEMPERATURE EFFECT: The temperature of the oils was varied by means of an oil-bath. The average breakdown strength was noted keeping the oil stationary through out the experiment.

TABLE - VIII

TEMPERATURE VS BREAKDOWN VOLTAGE AT DIFFERENT GAPS

Oil	Electrode gap (mm)	Temperature (°F)	Breakdown Voltage (kv)
Transformer	1	90	1.75
"	1	105	2.60
"	1	119	2.35
"	1	130	2.05
"	1	146	2.60
Transformer	2	90	6.80
"	2	100	8.00
"	2	109	11.00
"	2	116	14.40
Castor	1	94.0	3.50
"	1	108.5	4.10
"	1	130.0	3.80
"	1	137.5	4.20
Soyabean	1	97	2.25
"	1	108	2.50
"	1	111	2.60
"	1	115	3.45
"	1	130	3.90

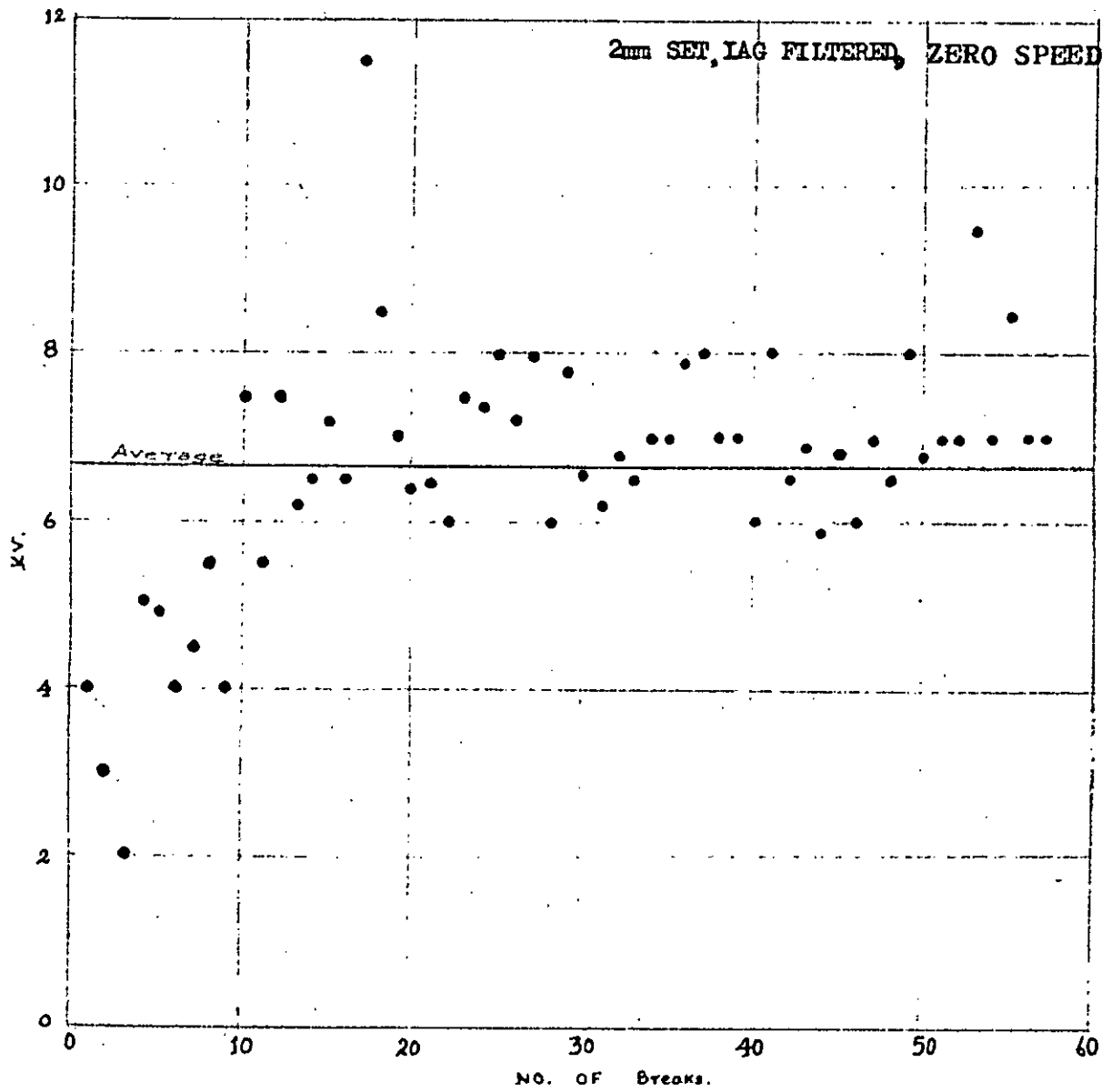


FIG.17 SUCCESSIVE BREAKS OF TRANSFORMER OIL

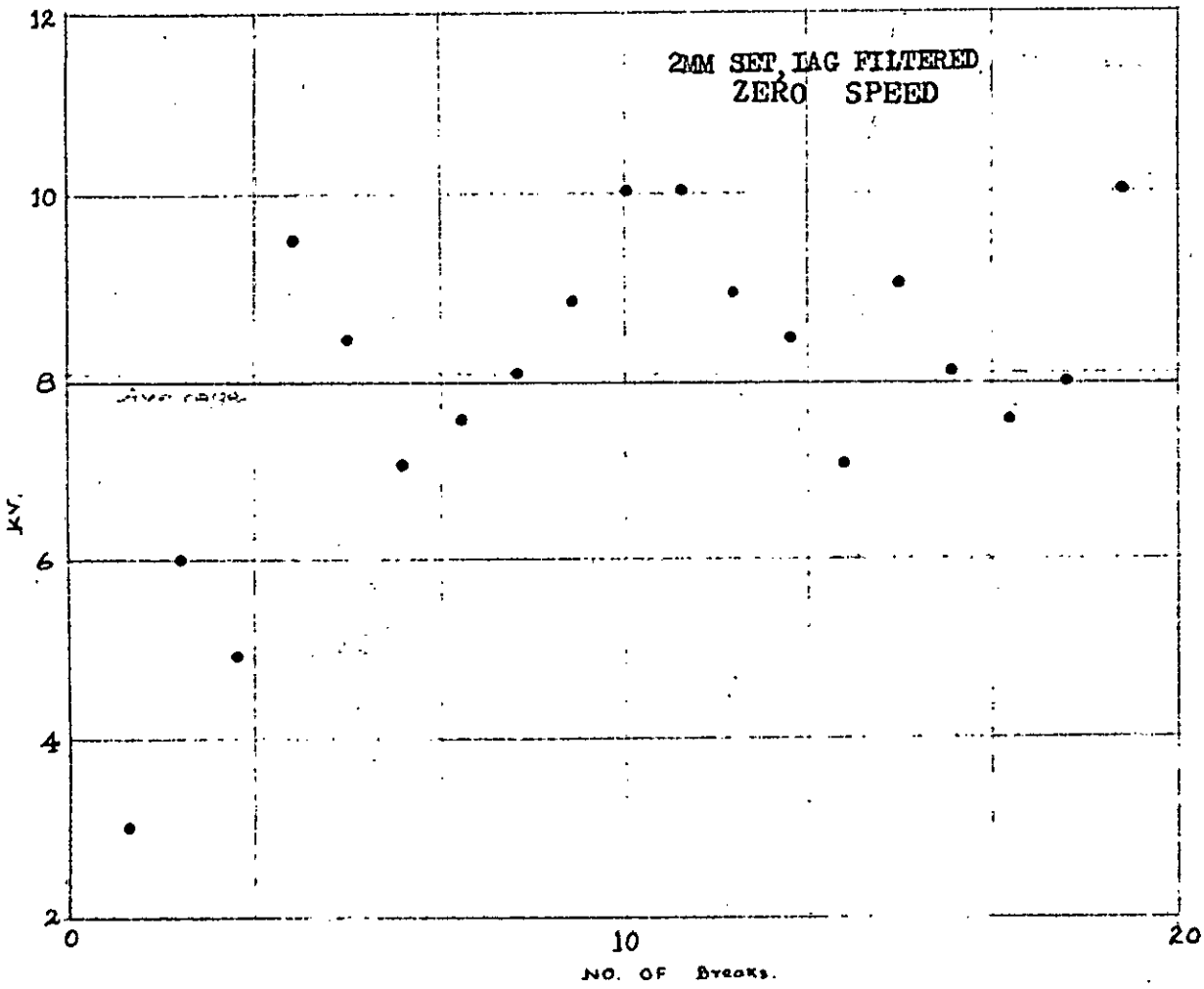


FIG.18 SUCCESSIVE BREAKS OF SOYABEAN OIL

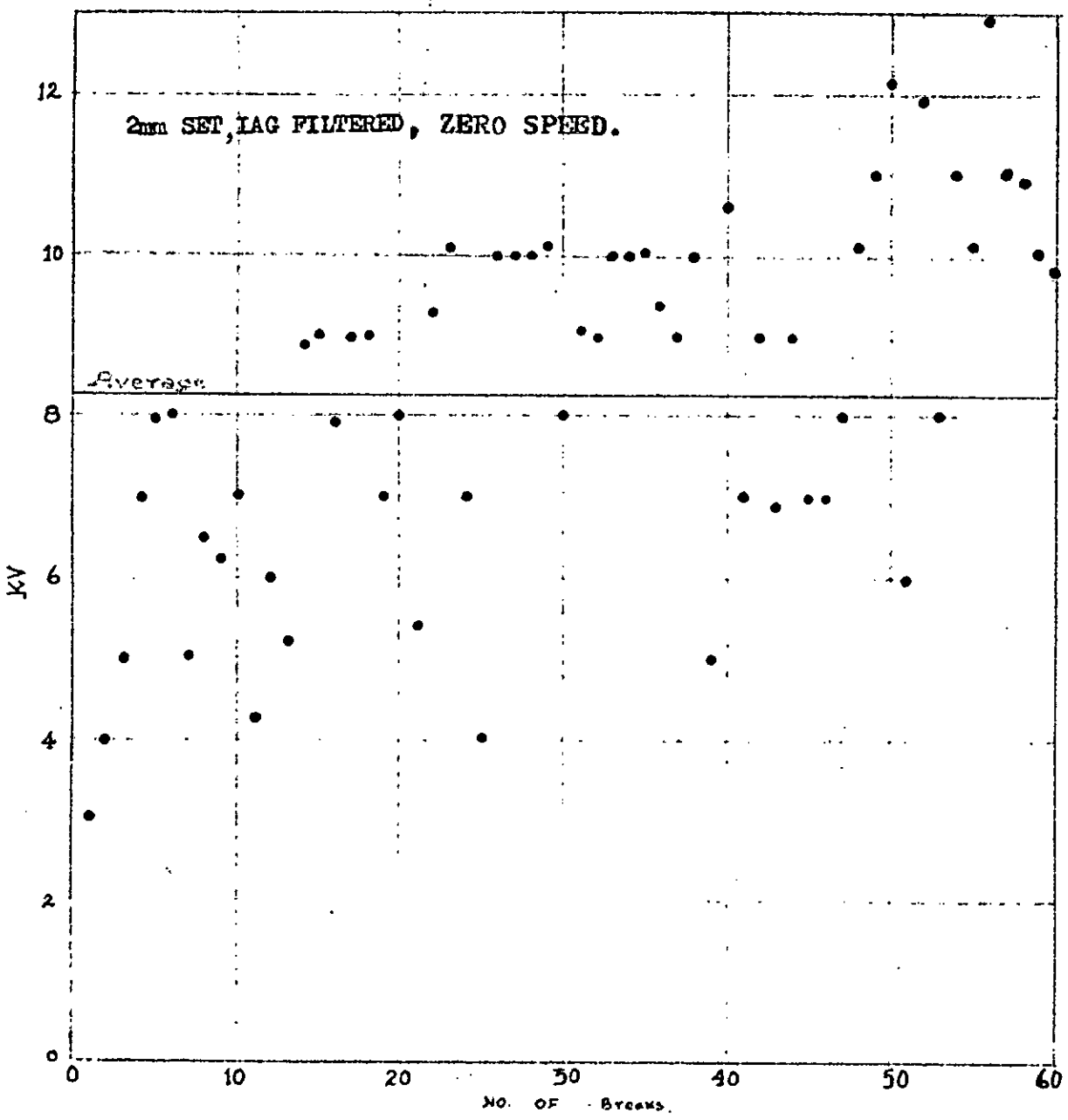


FIG.19 SUCCESSIVE BREAKS OF TRANSFORMER OIL

4.8 EFFECT OF SIMULTANEOUS TEMPERATURE AND AGITATION

TABLE -IX
TEMPERATURE VS BREAKDOWN VOLTAGE AT DIFFERENT SPEEDS OF AGIGATION.

Oil	Speed of agitation (rpm)	Electrode gap (mm)	Temperature (°F)	Breakdown voltage (kv)
Transformer	220	1	91.0	2.00
"	220	1	110.0	1.80
"	220	1	120.0	1.60
"	220	1	134.0	1.80
"	220	1	152.0	1.70
Transformer	440	1	96.0	3.00
"	440	1	101.0	2.05
"	440	1	130.0	2.00
"	440	1	153.0	1.90
Transformer	880	1	90.0	1.75
"	880	1	105.5	1.50
"	880	1	123.0	1.40
"	880	1	137.0	1.35
"	880	1	145.0	1.30
SOYABEAN	500	1	93.0	4.0
"	500	1	100.0	3.0
"	500	1	124.0	2.8
"	500	1	134.0	3.4
CASTOR	380	1	103	2.9
"	380	1	115	2.0
"	380	1	125	1.7
"	380	1	135	1.1
CASTOR	500	2	94	3.6
"	500	2	100	3.0
"	500	2	105	2.0
"	500	2	118	2.8
"	500	2	130	2.2

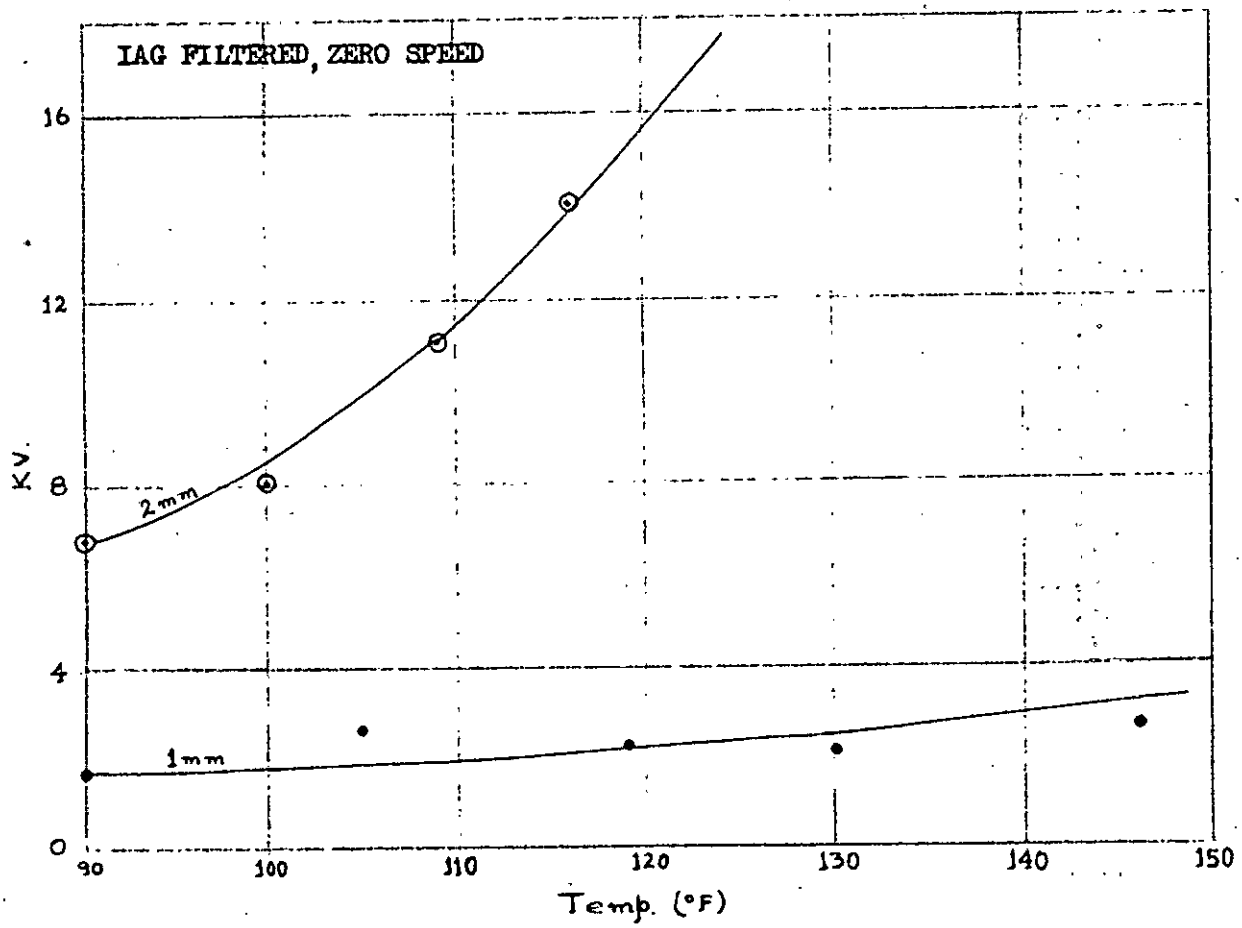


FIG. 20 TEMPERATURE TEST OF TRANSFORMER OIL.

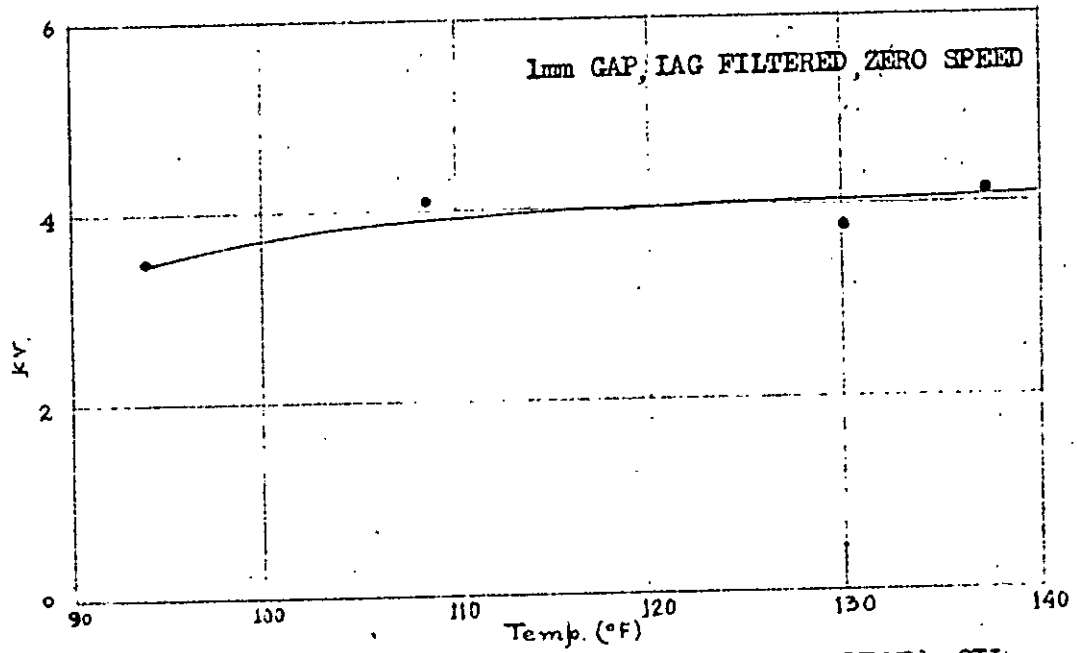


FIG. 21 TEMPERATURE TEST OF CASTOR OIL

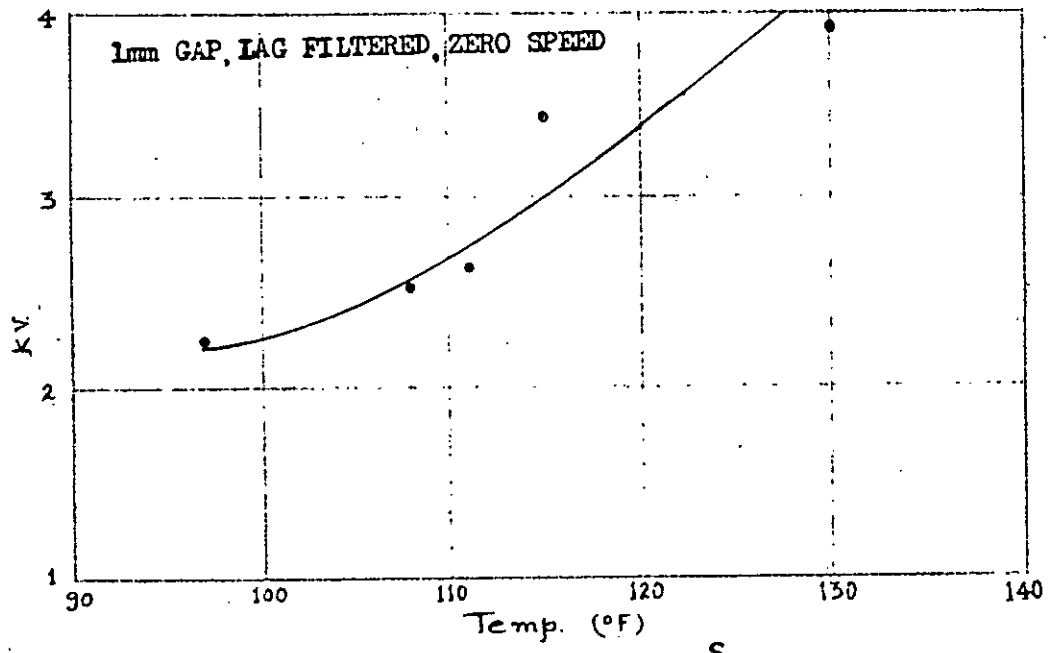


FIG. 22 TEMPERATURE TEST OF SOYABEAN OIL

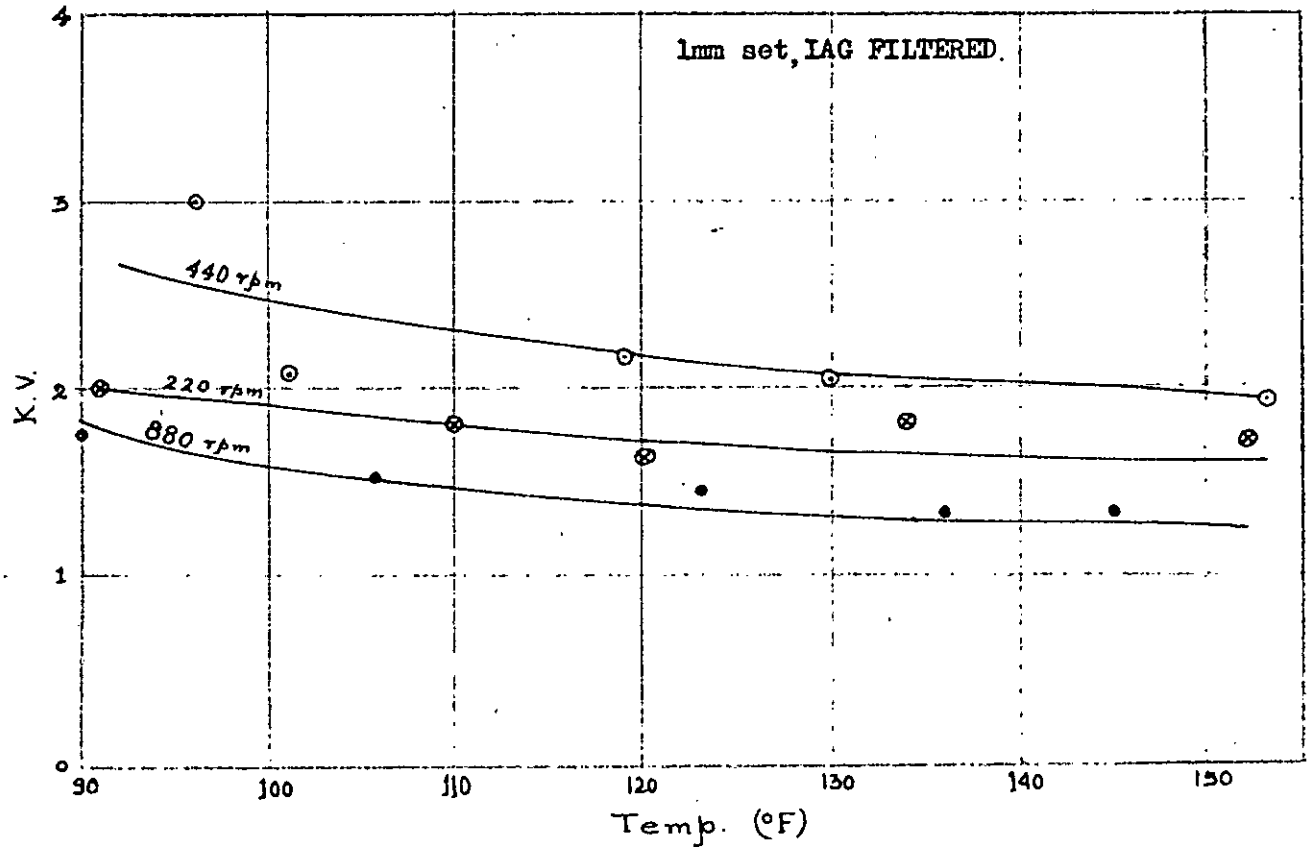


FIG. 23. TEMPERATURE AND SPEED TEST OF TRANSFORMER OIL

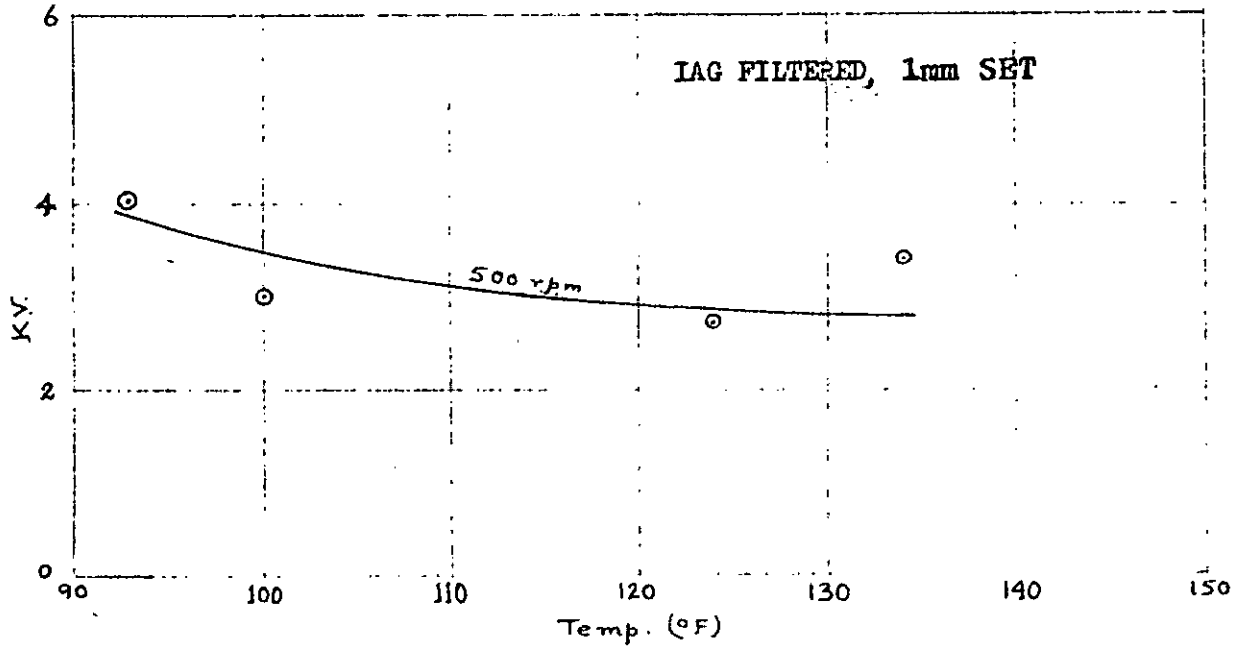


FIG. 24 TEMPERATURE AND SPEED TEST OF SOYABEAN OIL.

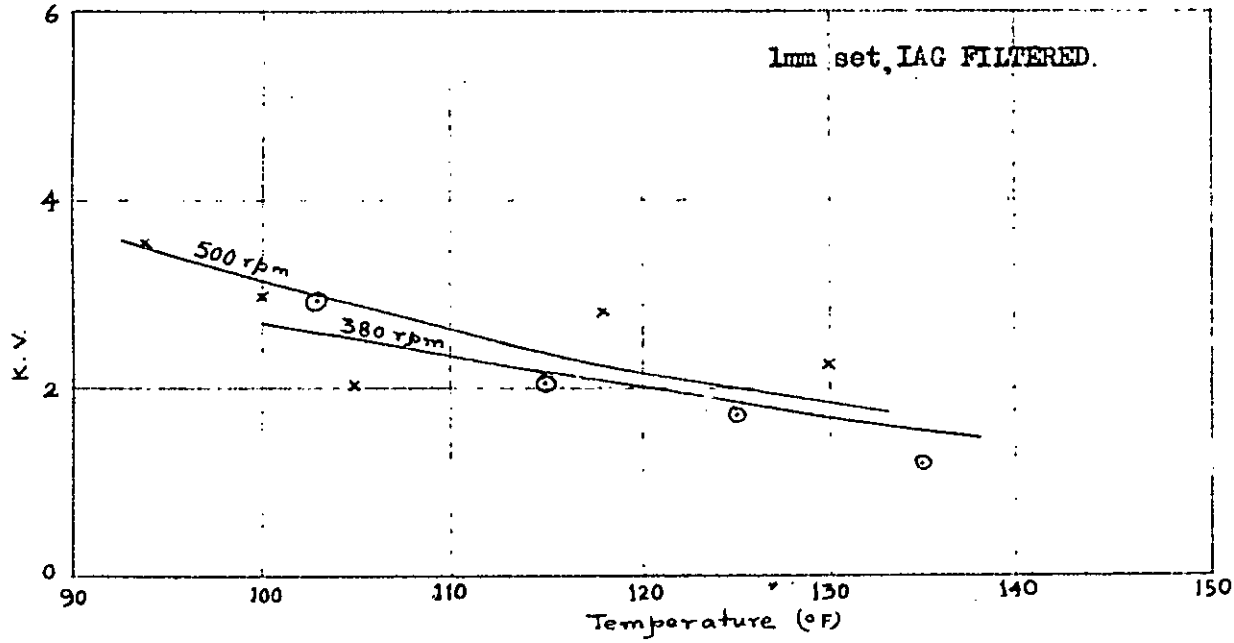


FIG. 25 TEMPERATURE AND SPEED TEST OF CASTOR OIL.

4.9 EFFECT OF TEMPERATURE ON STATIONARY AND AGIATED TRANSFORMER OIL.

The results are given in table X and plotted in figure 26.

TABLE X

COMPARISON OF STATIONARY AND AGITATED TEST OF TRANSFORMER OIL WITH TEMPERATURE VARIATION

Temperature (°F)	Breakdown voltage (When Agitated at 880 rpm) (kv)	Breakdown voltage (Stationery) (kv)
90	1.70	2.30
108	1.55	2.90
121	1.40	3.25
136	1.34	2.40
145	1.30	3.20

4.10 VISCOSITY VARIATION WITH TEMPERATURE: The procedure of viscosity measurement has been described in section 3.7. The specific gravities of the oils were first determined at room temperature and then these specifid gravities were converted at 4°c of H_2O by the use of Steam table [28]. The values of K and Sk are given in a chart with the viscosimeter manual. For Transformer and soyabean oils ball-3 was used but for castor ball-4 was used. The logarithm of viscosity has been plotted in the fig. 27 for convenience.

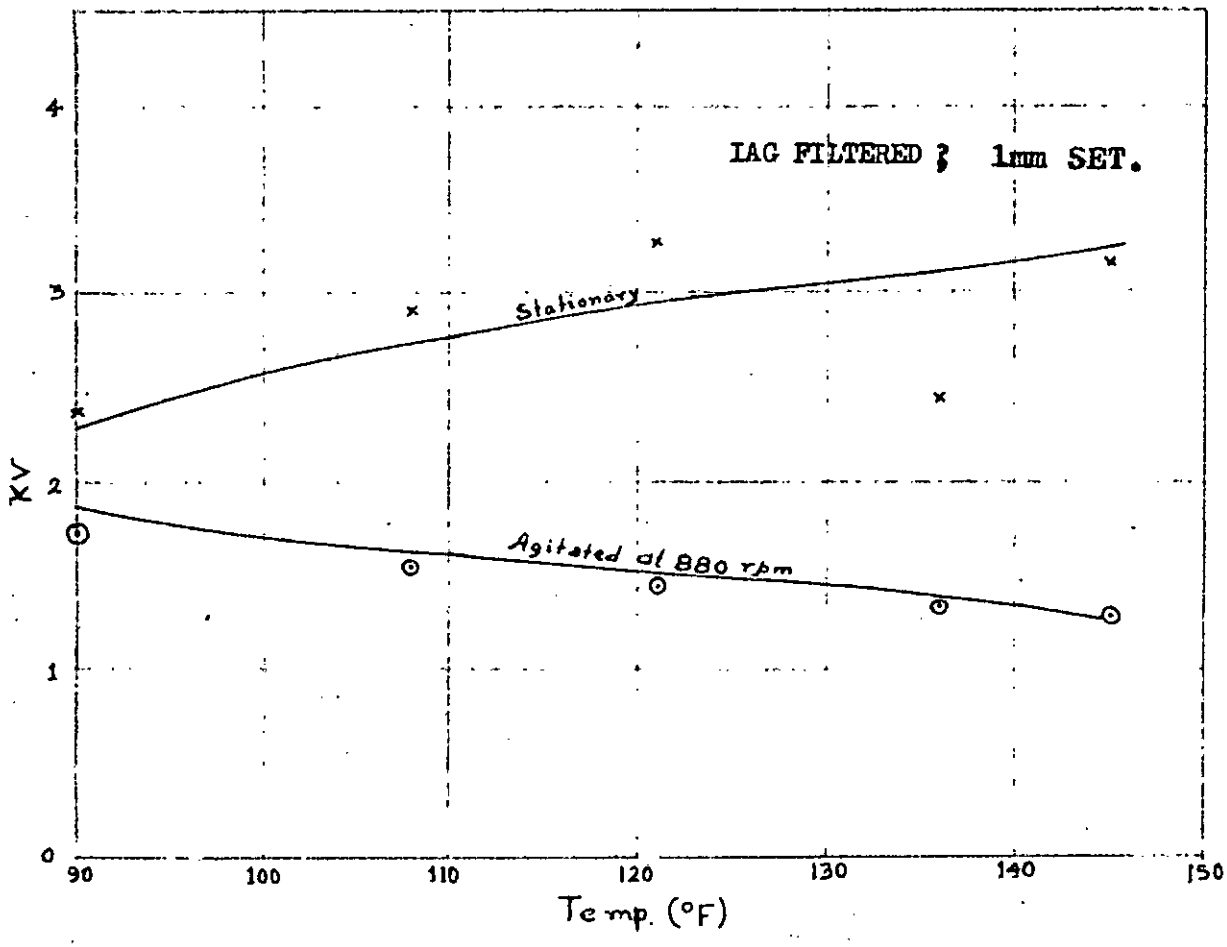


FIG. 26 STATION/SPEED AND TEMP TEST OF TRANSFORMER OIL

4.10.1 TRANSFORMER OIL:

TABLE XI-A

TEMPERATURE VS DISCOSITY

Tem. °C	Sp.Gr. at room temp.	Sp.Gr. at 40°C of H_2O(Sf)	K	S_k	F (Secs)	S_k-S_f	n-F(S_k-S_f)K	Logn
28.8	0.865	0.864	0.0734	8.151	33.00	7.307	17.70	1.248
35.5	0.860	0.856	0.0734	8.151	30.00	7.295	16.01	1.204
40.5	0.855	0.850	0.0734	8.151	28.00	7.301	15.01	1.176
55.0	0.840	0.830	0.0734	8.151	16.35	7.321	8.80	0.907
59.5	0.835	0.820	0.0734	8.151	16.20	7.331	8.72	0.941

4.10.2 SOYABEAN OIL:

TABLE XI-B

TEMPERATURE VS DISCOSITY

Temp. °C	Sp.Gr. at room temp.	Sp.Gr. at 40°C of H2O(Sf)	K	S_k	F (Secs)	S_k-S_f	n-F(S_k-S_f)K	Logn
34.0	0.902	0.900	0.0734	8.151	77.75	7.251	41.40	1.617
36.5	0.901	0.896	0.0734	8.151	75.00	7.255	40.00	1.602
43.0	0.900	0.895	0.0734	8.151	71.60	7.256	38.20	1.582
61.5	0.883	0.872	0.0734	8.151	49.00	7.279	26.15	1.417

4.10.3 CASTOR OIL:

TABLE XI-C

TEMPERATURE VS VISCOSITY

Temp. °C	Sp.Gr. at room temp.	Sp.Gr. at 40°C of $H_2O(S_s)$	K	S_k	F (Secs)	S_k-S_f	$n-F(S_k-S_f)K$	Logn
37.0	0.945	0.940	0.520	8.140	380.45	7.200	1480.00	3.170
41.0	0.943	0.937	0.520	8.140	288.00	7.203	1080.00	3.003
50.0	0.940	0.930	0.520	8.140	240.55	7.210	902.00	2.954
53.0	0.938	0.926	0.520	8.140	225.50	7.214	844.00	3.926

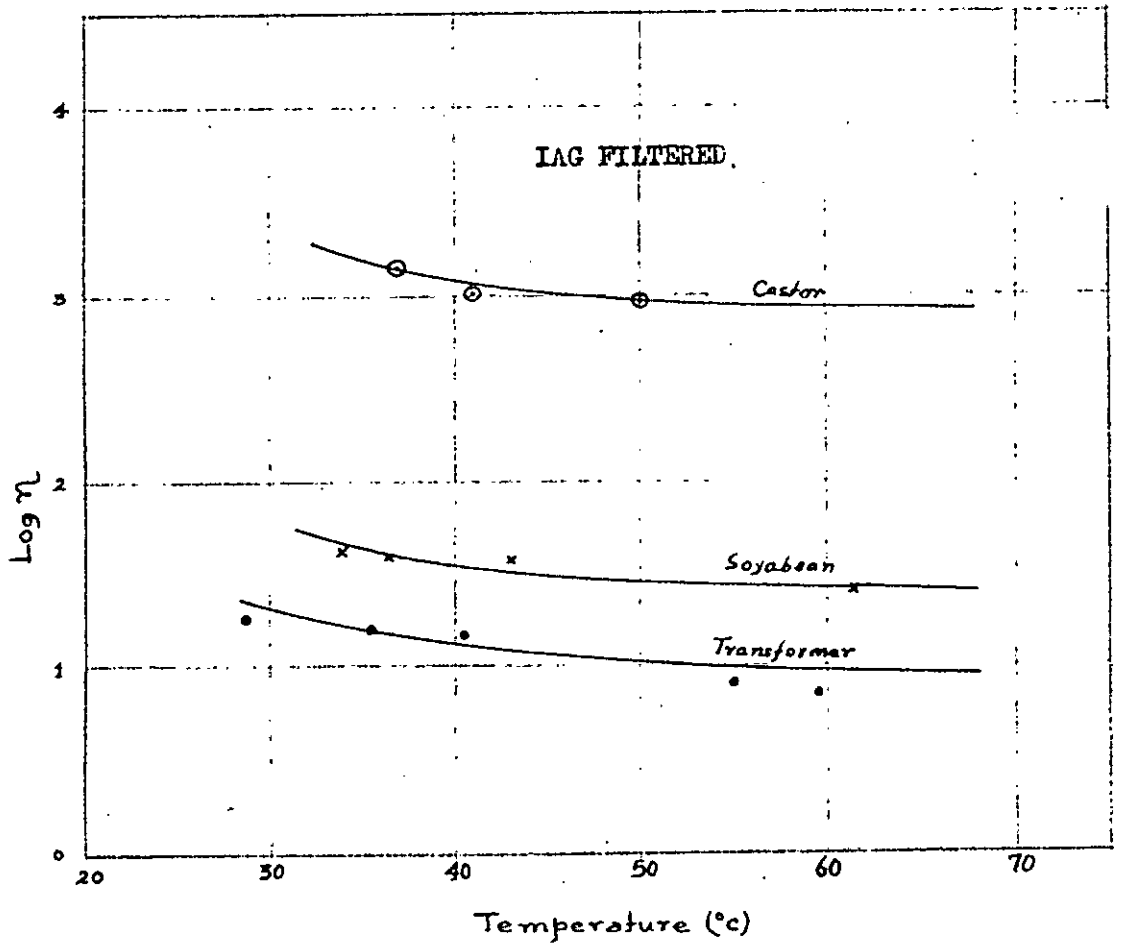


FIG.27 VISUSITY OF OILS

5. DISCUSSION OF RESULTS

Some of the results of the present work have lent support to the breakdown theory that breakdown in oil occurs in the gaseous phase. For a comprehensive understanding of this aspect of the results a brief review of the pertinent physical events that take place prior to and during breakdown are given below.

As the voltage between the electrodes is increased the particles in the oil begin to oscillate in the gap. Occasionally the particles form bridges across the electrode gap which results in electric breakdown at very low voltages. But the most important event that takes place is the formation of surface barriers and space charge layers adjacent to the electrodes. It is postulated that electr-ons are emitted from the cathode. The emitted electrons are accelerated in the barrier and space charge layer adjacent to this electrode and are ejected into the liquid where they are further accelerated by the external applied field between the electrodes. These electrons by this process gains considerable kinetic energy. When such an electron collides with a molecule of the liquid, ioniza-tion or dissociation takes place. The dissociation energy of a hydr-carbon bond is 3.78 ev and the ionization energy is about 10 ev. It is, therefore, probable that dissociation will occur first by the high velocity electron originated from the cathode. Hydrogen as one of the dissociation products will tend to form bubbles. The hydrogen may be absorbed by the oil, if the oil contains unsaturated hydrocarbon groups. With increasing fields this process would continue until the

gas evolution is greater than the ability of the surrounding liquid to absorb it. A bubble may, then form and the acceleration of electrons within the bubble with lead to further dissociation so that the bubble may rapidly grow. Additional positive and negative ions will be formed in this region enhancing the space charges at the electrodes, which in turn will introduce greater number of electrons and positive ions. The process being unstable in nature would continue till the final breakdown takes place. The dissolved gases in the test oil may also become detached by the impact with the high energy electrons. This may also lead to nucleation and bubble formation which, in turn, may quicken the breakdown processes of the oil.

The results of the present investigation which are important for the above hypothesis are the curves in figures 11, 12, 13, 20, 21 and 22. The curves in fig. 11 fig.12 and fig.13 indicate that the dielectric strength of the oils decreases with the increasing speeds of agitation of the oils. [The general molecular structure of the types of oils tested are given by formulac ( ) such as C_2H_{2n-2} and C_2H_{2n}] Hydrogen bubbles are formed by (1) the dissociation processes discussed previously. (2) And gas is also formed because of the velocity gradient in the liquid film; the layers of oils closer the rotating electrode have higher speed than those closer the stationary electrode. The higher speed layer would dislodge the dissolved and/or suspended gas molcules from the lower speed layers by friction. The hydrogen bubbles being very light begin to move up to escape to the atmosphere. But the hydrogen bubbles and air molecules cannot escape, because of the Bernoulli's theorem. Which states ( ) 'for any mass of flowing liquid in which there is a continuous

/connecion between all the particles, the total head of each particle is the same'. Therefore if velocity head increases, the pressure head decreases. The gas molecules tends to accumulate in the lower pressure region, which is near the rotating electrodes where the spped is the highest. The gas molecules are again broken by the rotating electrode. These broken gas bubbles take part in the dissociation and ionformation activity at different parts of the test liquid. This enhanced dissociation, nucleation and ion-formation activity quickans and, therefore, lowers the breakdown strength of the liquid.

It has been found that the viscosity of transformer oil is the lowest, that of castor is the highest and the viscosity of soyabean is intermediate (Fig.27). Castor oil being more viscous than that of either transformer or Soyabean, its velocity gradient will be highest. Therefore, it has greater ability to dislodge the suspended gas molecules by surface friction between layers. But the gas molecules movement towards region of higher speed would be slower. Whereas in the least viscous Transformer oil, the velocity gradient is lower and therefore, the dislodgement of suspended gas molecules shall be less but here, the gas movement and accumulation to regions of higher speed shall be faster. For this reason the breakdown strength of less viscous oil, such as transformer, shall fall faster with speed than that of the more viscous ones. This can be noticed from the curves in figures 11,12 and 13. The slopes of the curves of Transformer oil are the highest, those of Castor oil are least and those of Soyabean are in between them.

Any process, which shall help the bubbles to be released quickly, will enhance the breakdown strength of the liquid. The rise of temperature drives out the absorbed gases as well as the hydrogen gas bubbles formed from the dissociation by the high energy electrons. And thus the breakdown strength of the oil increases. This is confirmed from the curves for stationary oils in fig.20, fig.21 and fig.22. But as soon as the oil is agitated the gas molecules are trapped in the mass of the liquid, and they lower down the breakdown strength as discussed previously. This simultaneous effect of temperature and agitation is shown in Fig.23, Fig.24 and Fig.25.

The formation of gas by dissociation was particularly noticed in the case of castor oil. During the conduction of the experiments with this oil, it was observed that the volume of the oil increased in the annular space between the electrodes.

Characteristics of successive stationary breaks of Transformer, Soyabean and Castor oils are shown in Fig.17, Fig.18 and Fig.19. In all these figures it should be noticed that all the initial breaks are much below the average value. This is so, because of the particle activity, that is, due to its oscillation and bridge formation between the gaps reference to which has been made at the beginning of this discussion. The Fig.14, Fig.15 and Fig.16 are interesting. They are for intermittently agitated oils. It will be noted from these curves that successive interval of breaks have a tendency to give a higher value for the breakdown voltage. The agitation helps in the mixing of dissociated carbon part icles evenly through out the liquid. This discourages the

formation of bridges when the liquid is stressed under steady state after an agitation.

The results of higher gap settings and higher grades of filtration could not be included inspite of the best endeavour of the author. At higher filtration and gap distances there were air breakdown at the edges of the electrodes, between the electrodes and the metallic disc.

A few comments on the shape of electrodes used in the present work, seem warranged. Becuase of the irregular shape of the electrodes, the f ield was not uniform, as in the case the standard spherical electrodes. The breakdown strengt hs therefore, do not represent the actual strength of the oils studied. They represent the relative values, because different oils have been studeid with the same electrodes and under similar conditions. The nature of the investigation and necessary experiments dictated the shape of electrode a chosen, where not much could be done to remove edges effectively. Moreover in practical case, the rotating parts of an electric machine, which may carry potentials may be of any shapes and configurations. Many modifications, therefore, can be made as to the electrode shapes. But the present investigation has definitely found out the trend of breakdown voltages under different conditions of agitation and temperature variation. Another point that needs mention is that there was a very small amount of eccenticity between the concentric electrodes. Inspite of best efforts, perhaps a slight eccenticity would not have been eliminated. It is estimated that the error due to this was negligible.

6. CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

Investigation in this Laboratory is going on for sometime to find out a good locally available insulating oil. The present work is a step in this direction. The results of this investigation show that Soyabean oil has good insulating property comparable with that of transformer oil. Like the transormer oil, the Soyabean oil shows a tendency to assume an uniform value. Its behavious is not erratic like that of Castor oil. In some electric machines the insulating oil does the work of cooling for the heat generated by hysteresis, eddy-current and such other losses. In these applications, the transformer oil being less viscous, would be a more efficient cooler than Soyabean oil. Nevert heless, if other things (3) (18) are found suitable, Soyabean can be used as a good insulating oil where cooling is not a great problem.

An useful step towards the introductions of motion in the dielectric during a breakdown process has been taken. Further studies are being planned in which breakdown in this liquid film under different degrees of vacuum, and uniform rates of agitation will be investigated, It is estimated that variations in the degree of vacuum control the quantity of dissolved gas in the liquids, and effects of agitation would be more or less marked depending on circumstances.

T 18

REFERENCES

(1) Clark, F.M. — J.Franklin, Inst.215,39,(1933)

(2) Clark, F.M. — J.Franklin, Inst.216,429,(1933)

(3) Childs, D.G. & others — Proc.I.E.E.Pt.IIA, 3, 1953

(4) Darveniza, M. — Ph.D.Thesis,London University,(1959)

(5) Darveniza, M.& Tropper,H. — Proc.Phys.Sec.78, 854, (1961)

(6) EL-Dine,M.E.& Tropper,H. — Proc.I.E.E.Monograph 1355(1955)

(7) Gosling, O.H. — Ph.D. Thesis, London University, (1960)

(8) Green, W.B. — Jr. of Appl. Phys. 26, 1257,(1955)

(9) Henry L.Alder & Roessler — Introduction to Probability and Statistics (book),

(10) Huq, A.M.Z, — Ph.D.Thesis, London University, (1962)

(11) Huq, A,M.Z. and Tropper,H. — Brit.Jr. of Appl.Phys. 15, 1964

(12) Hasan, M. — B.Sc.Engg.Project,E.P.U.E.T., (1965)

(13) Ibrahim, M. — Jr. of P.C.S.I.R., 25, 1963

(14) Immanuel Estermann — Methods of Experimental physics (book),

(15) Khambanonda, A. — Ph.D. Thesis, London University,(1958)

(16) KOK, J.A. — Electrical Breakdown of Insulating Liquids (book)., Bilips Technical Library (1961)

(17) Mac Conochie,I.O.& Cameron — Jr.of Appl,Mechanics, 82, 1956

(18) Martia, R.G.& Patherson,E.A. — Proc. I.E.E. Pt.II A. 1953

(19) Millman & Silly — Electronics (book)

(20) Noorul Hasan, Syed — B.Sc.Engg.Project,E.P.U.E.T.,(1958)

(21) Lewit — Hydralics(book)

(21") Langerer — Proc. I.E.E. 112, 1965

(22) Sletten,A. — Nature, 183, 311, (1959)

(23) Swan,D.W.and Lewis,T.J.J. — Electrochem. Sec.107, 180, (1960)

(24) Swan, D.W. — Proc. Phys. Sec.78,422,(1961)

(25) Sharbangh,A.H.,Bregg.I.K.& Crowe,R.W., Jr.of Appl.Phys.4,26, 1955

(26) Van der Waarden, M. J.Collid,Science,5,448,(1950)

(27) Watson, P.K. & Higham Proc.I.E.E.100,Pt.IIA,168,(1953)

(28) William, H.McAdams Heat Transmission(book)