International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 4, Issue 1 (January-February, 2016), PP. 144-150

TRACKING AND EROSION RESISTANCE OF RUBBER BLENDS FOR HIGH VOLTAGE INSULATORS

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***Abstract*—High voltage insulators are essential for the reliable performance of electric power systems. Polymeric insulators are widely used as outdoor H.V insulators. In the presence of heavy polluted and wet condition, resistance to vandalism and high dielectric strength voltage. Polymer insulators particularly those made of Ethylene Propylene Diene Monomer and silicone rubber are increasingly being used today. Blending of two polymers is an attractive way to develop a new material combining the best properties of these two materials. In 1986 the first alloy of silicone rubber/EPDM was prepared. Today the most widely used insulators weather shed materials are silicone rubber /EPDM blends. This paper aims to improve silicone rubber /EPDM blends electrical properties by adding SiR to EPDM in different percentages. Also aims to study dielectric strength and tracking resistance under several conditions of SiR/ EPDM blend samples. Then trying to find an appropriate weight percentage composition of such blend in order to enhance the dielectric strength and tracking resistance in different conditions.**

***Index Terms*—Polymeric Insulators, Rubber Blends, Tracking Resistance, Dielectric Strength.**

I. INTRODUCTION

Outdoor insulating bodies have traditionally been made out of glass of porcelain materials. The development and use of polymeric insulators started during the 1960s [1, 2].

Polymeric insulators are increasingly being used in the distribution and the transmission voltage ranges are steadily capturing a wider share of the market [3, 4].

The use of insulators made of polymeric materials for lines and stations has increased significantly in the last twenty years. Various reasons such as non-explosive failure mode superior vandal resistance due to the flexible material superior contamination performance due to hydrophobicity especially for silicone rubber - SIR), lower lead times and installed costs are some of the reasons for their increased popularity, when compared with traditional porcelain and glass products. However, the degradation resistance of polymers towards electrical discharges is decidedly inferior to inorganic porcelain and glass. Tracking and erosion are the modes of failure and they are due to the localized heat generated by the discharges. Users are therefore concerned about the remaining life of such devices [5, 6].

Polymeric insulators are being accepted increasingly for use in outdoor applications. The tremendous growth is due to their advantages over the traditional ceramic and glass insulators. It includes lightweight, higher mechanical strength to weight ratio, resistance to vandalism, better performance in the presence of heavy pollution in wet condition, and better withstand voltage than porcelain insulators. Because polymeric insulators are relatively new, the expected lifetime and their long-term reliability are not known, and therefore are of concern to users.

The typical parts/components of a polymeric insulator are core/rod, metal end fittings/rings and polymer housing/weather sheds. Here, the fibre glass or ceramic rod is employed for mechanical strength and electrical strength under dry conditions. Fibre glass is a poor insulator under wet conditions, as it absorbs moisture. To overcome this limitation of intrinsic core, the housing is installed over the core with a suitable and stable interfacial sealant to maintain dielectric strengths. Proper end fittings are provided for connections to pole and conductor. Housing material made of Silicone and EPDM rubber for a polymeric insulator is the target of this research work.

EPDM elastomer possesses good mechanical strength and outstanding resistance to attack by oxygen, ozone and weather. It has excellent dielectric properties even at high temperatures. Silicone elastomers have excellent dielectric properties coupled with high temperature stability. Blending of two polymers is an attractive way to develop a new material with good dielectric characteristics, thermal stability, and resistance towards polluted environment [8, 7].

The insulators made from polymeric materials offer numerous advantages in outdoor insulation systems due to their good dielectric properties, light weight, better pollution performance, low cost, quicker processing etc. However, they can be degraded by environmental stress like heat, moisture, contaminants and this could lead to tracking and surface discharges which ultimately cause flashover of the insulator, Tracking, which is mainly due to heat of electrical discharges across dry bands or in the presence of wet contaminant layer on the insulator surface, remains to be the most serious problem.

A track is a partially conducting path of localized deterioration on the surface of an insulating material. The environmental stress plays a part in the mechanism that causes a failure to occur. When the environment includes rain, fog, salt, any condensate or contaminant, the type of deterioration differs. Blending of Silicone rubber with EPDM in a composition of 50: 50 by weight was done in a laboratory model, two roll mill for 5 minutes at room temperature. A curing agent of DCP (3phr) and various percentages of silica filler were added during the mill mixing. The blended compounds were vulcanized in a hydraulically operated press at (443 k) and 10 minutes as per the usual procedure. Then the vulcanizates were postcured for 2 hours at (423 k) in an air circulated oven. Sheets of 3mm thickness were prepared by the above procedure and test samples were punched out from the sheets [9, 10].

This paper aims to improve silicone rubber /EPDM blends electrical properties by adding SiR to EPDM in different percentage. It focuses on trying to find an appropriate weight percentage composition of such blend in order to enhance the dielectric strength and tracking resistance in different conditions. Soft program (Curve fitting) was used to interpret the equation between different conditions.

II. EXPERIMENTAL AND PROCEDURES

A. Sample Preparation and Dimensions

Five blend percentages have been prepared: 100% EPDM, 100% SiR, 25%EPDM with 75% SiR, 50% EPDM with 50% SiR, and 75%EPDM with 25% SiR. Table 1 shows the mixing formulation. The blends were carried out in a laboratory model two roll mill (470 mm diameter and 300 mm working distance). The gap between two rolls changed from 1mm to 3mm according to the mixing conditions. The speed of the slow roll is 24 rpm with a gear ratio 1:1.4. First, rubber was masticated and then dicumyl peroxide was added. The blends were left overnight before vulcanization. In the experiment using two different forms of samples. First sample is in the form of a disc and their standard thickness is 1mm for measuring dielectric strength. Second Sample is in the form of plate with dimension (120x50x6) mm for measuring tracking resistance.

TABLE 1. MIXING FORMULATION

Sample Symbol	SiR (%)	EPDM (%)
A	0	100
B	25	75
C	50	50
D	75	25
E	100	0

B. Electrical Test Supply and Electrodes

The A.C high voltage obtained from a single-phase high voltage transformer (100kV-5kVA). The output voltage of the transformer is controlled smoothly by a (0-220 V) variac regulating panel, the voltage applied to its primary winding. The high voltage set-up has been enclosed in an earthen cage. The power supply was connected in series with two electrodes.

C. Tracking Resistance Test

Tracking resistance is determined as per IEC-60587. A schematic diagram of the experimental setup used in the work shown in the Fig. 1.The distance between the top and bottom electrodes are adjusted to be equal to 50 mm and 4.5 kV is applied and used types of sodium chloride contamination and ammonium chloride.
Peristaltic pump is used to control the flow rate of contamination. The relation (equation) between different conditions was interpreted by the MATLAB.

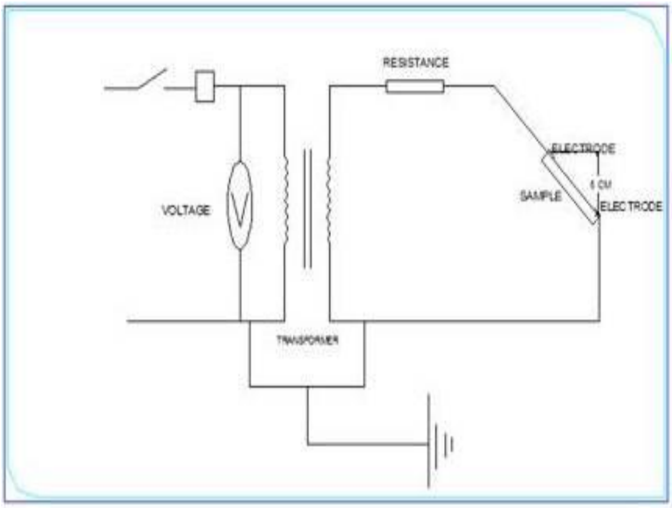

Fig 1. Schematic diagram used for tracking resistance test.

D. Dielectric Strength Test

All insulating materials fail at some level of applied voltage for a given set of operating conditions. The dielectric strength is the voltage that an insulating material can withstand before dielectric breakdown occurs. Dielectric strength is normally expressed in voltage-gradient terms, such as voltage per thickness (kV/mm). According to ATSM DI49-64, the dielectric strength sets of SiR, EPDM and their blends specimens have been evaluated.

Dielectric strength is the voltage gradient at which electric failure results. The failure is characterized by an excessive flow of current (arc) and by partial destruction of the material. Dielectric strength is measured through the thickness of the specimen which is equal 1 mm, and is expressed in volts per unit of thickness. Figure 2 shows dielectric breakdown strength test.

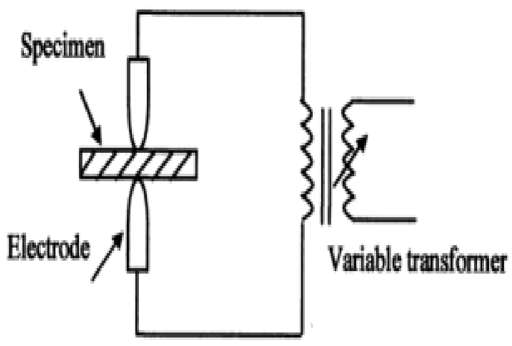

Fig 2. Dielectric breakdown strength test.

E. Test Procedures

In tracking resistance test when the power frequency AC voltage source is connected to the top electrode, current flows in the conductive paths formed by the contaminant (between top and bottom electrodes) cause partial evaporation of the contaminant by creating dry band in the gap. The partial discharge forms spark across the dry band. Continuous flow of the contaminant in the gap deviates the surface flow and the above process was repeated. The spark across the dry band results in temperature rise and gradual heating of the specimen. This rise in temperature with local reaction of the material along with the contaminant considered to be responsible for erosion of the material followed by tracking process. In fig. 3 shows tracking resistance test in laboratory.

Fig 3. Tracking arc processes at H.V laboratory.

In dielectric strength of the blended sample determined as per IEC-60243-1 (ASTM D 149) standard at 250 V and 50 Hz. and thickness of the samples are 1mm. Test specimen was placed between two electrodes and the voltage increased until the dielectric breakdown occurring. The voltage at which dielectric breakdown occurs is read as dielectric breakdown voltage.

III. RESULTS AND DISSCUSION

A. Experimental Results of Tracking Resistance

The tracking resistance for SiR/ EPDM blends was studied in different conditions (salty wet and acid rain) in different percentage of SiR (0%, 25%, 50%, 75% and 100%). Figure 4 shows the comparison between tracking resistance time and silicone rubber/EPDM blends under salt wet and acid rain conditions.

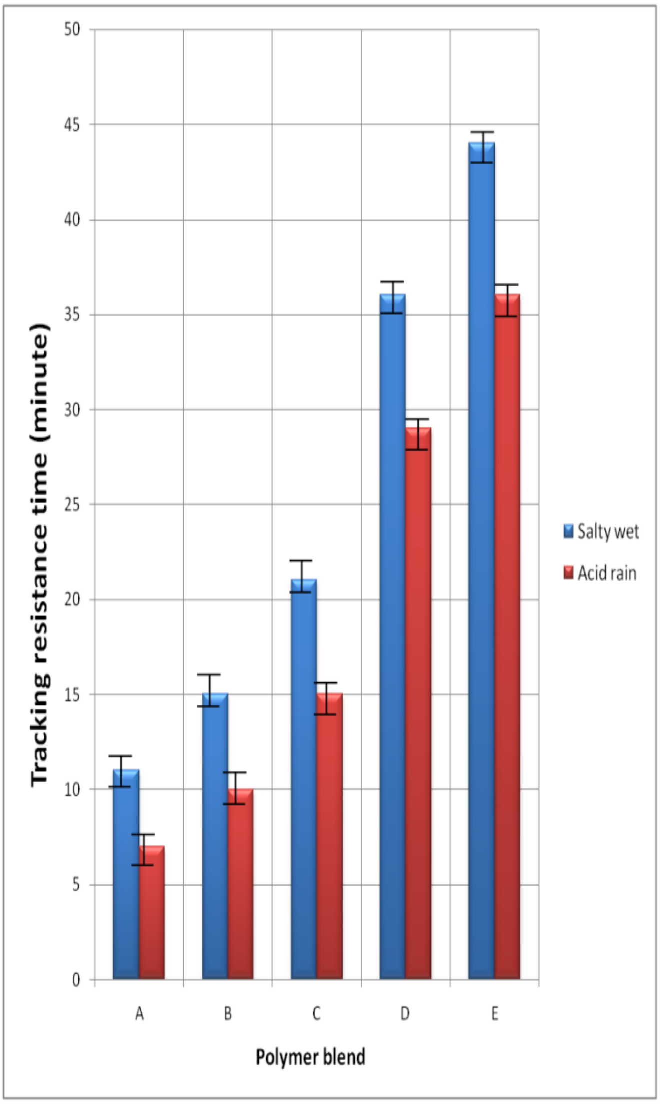

Fig 4. Tracking resistance time (minute) of blend samples under salt wet and acid rain condition.

At (sample A), the tracking resistance time decreased from 11min for salt wet case to 7min for acid rain condition. The percentage of tracking resistance time losses is 36.3%.

At (sample B), the tracking resistance time decreased from 15 min for salt wet case to 10 min for acid rain condition. The percentage of tracking resistance time losses is 33.3%.

At (sample C), the tracking resistance time decreased from 21min for salt wet case to 15 min for acid rain condition. The percentage of tracking resistance time losses is 28.5%.

At (sample D), the tracking resistance time decreased from 36 min for salt wet case to 29 min for acid rain condition. The percentage of tracking resistance time losses is 19.4%.

At (sample E), the tracking resistance time decreased from 44 min for salt wet case to 36 min for acid rain condition. The percentage of tracking resistance time losses is 18.2%.

It can be concluded from fig. 4 that the test results shows the increasing proportion of silicone rubber enhance the tracking resistance. The tracking resistance decreased from salty wet to acid rain. Tracking accelerates in acid rain about salt wet.

B. Experimental Results of Dielectric Strength

The dielectric strength for SiR/ EPDM blends was studied in different conditions (dry, wet, salty wet and very salty wet) in different percentage of SiR (0%, 25%, 50%, 75% and 100%). Figure 5 shows the comparison between dielectric strength test for silicone rubber/EPDM blends under all conditions (dry, wet, low salinity and high salinity).

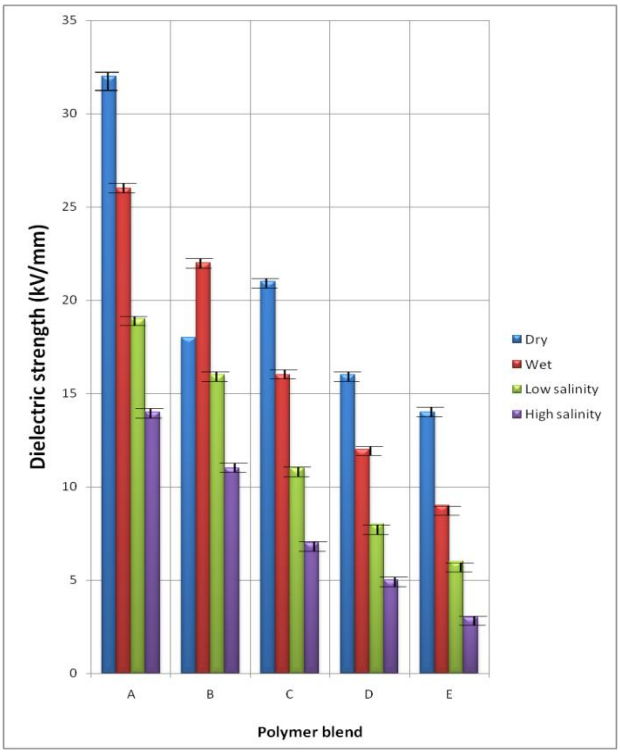

Fig 5. Dielectric strength (kV/mm) of blend samples under various conditions.

In wet conditions for (sample A), the dielectric strength of the blend samples decreased from 32.25kV/mm in dry condition to 26.13kV/mm in wet condition. The percentage of dielectric strength losses is 19%.

In low salinity for (sample A), the dielectric strength of the blend samples decreased from 32.25kV/mm in dry condition to 19.3kV/mm in low salinity condition. The percentage of dielectric strength losses is 41%.

In high salinity for (sample A), the dielectric strength of the blend samples decreased from 32.25kV/mm in dry condition to 14.02kV/mm in high salinity conditions. The percentage of dielectric strength losses is 56%.

In wet conditions for (sample E), the dielectric strength of the blend samples decreased from 14.2kV/mm in dry condition to 9.07kV/mm in wet condition. The percentage of dielectric strength losses is 36%.

In low salinity for (sample E), the dielectric strength of the blend samples decreased from 14.2kV/mm in dry condition to 6.32kV/mm in low salinity conditions. The percentage of dielectric strength losses is 57%.

In high salinity for (sample E), the dielectric strength of the blend samples decreased from 14.2kV/mm in dry condition to 3.22kV/mm in high salinity conditions. The percentage of dielectric strength losses is 79%.

It can be observed that, increasing weight percentage of EPDM improves the dielectric strength of the blends. The dielectric strength decreased from dry condition and from wet condition and from low salinity condition and from high salinity conditions. Because of the water and salinity caused leakage current.

It can be interpreted from fig. 4 and fig. 5 that using SiR/ EPDM blends in different percentages improves electrical properties.

C. Soft Program (MATLAB) Results in Tracking Resistance Test

Curve fitting methods allow you to create, access, and modify curve fitting objects. That allowed to like plot and integrate, to perform operations that uniformly process the entirety of information encapsulated in a curve fitting object.

Figure 6 shows curve fitting for the tracking resistance time results for the samples under salt wet condition.

Where y is the tracking resistance time (minute) under salt wet, x is the percentage of SiR in blend.

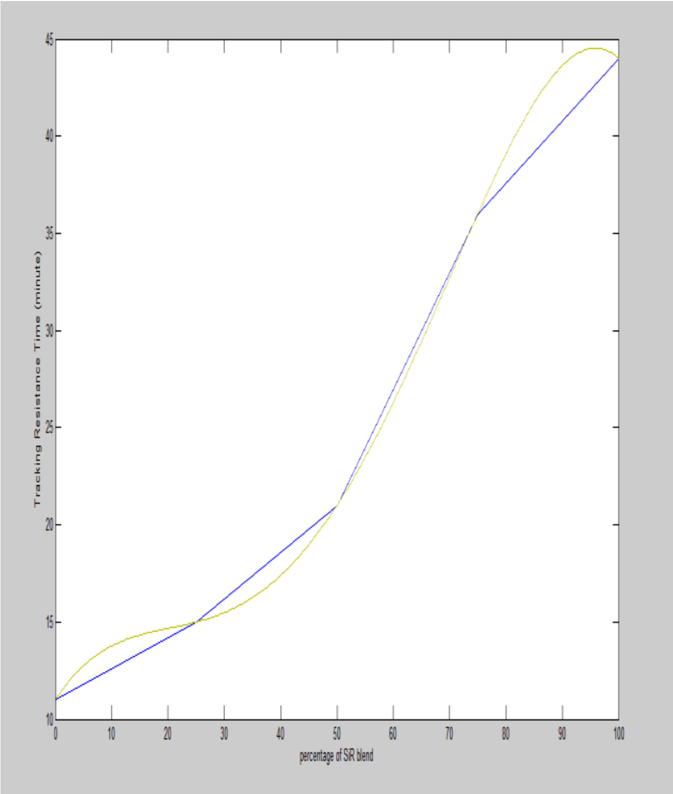

Fig 6. Curve fitting results for the tracking resistance time (minute) of blend samples under salt wet conditions.

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial equation as follow:
Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5

Coefficients
P1 = -2.4533e-006
P2 = 0.00044267
P3 = -0.020867
P4 = 0.44333
P5 = 11

Figure 7 shows tracking resistance time (minute) of blend samples under acid rain condition by using curve fitting. From the figure it can be observed that the tracking resistance time decreases with the increasing percentage of EPDM, This can be attributed to that the surface roughness of EPDM is rougher than that of SiR which accelerates the tracking to occur.

Where y is the tracking resistance time (minute) under acid rain, x is the percentage of SiR in blend.

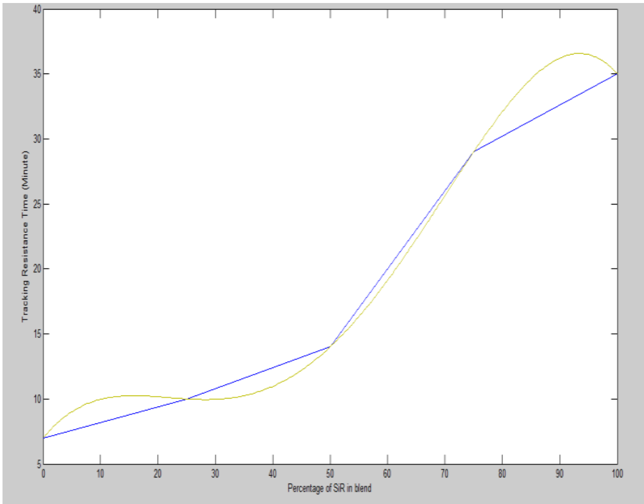

Fig 7. Tracking resistance time (minute) of blend samples under acid rain condition by using curve fitting

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial equation as follow:
Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5
Coefficients
P1 = -3.2e-006
P2 = 0.00058667
P3 = -0.0292
P4 = 0.53333
P5 = 7

D. *Soft Program (MATLAB) Results in Dielectric Strength Test*

Figure 8 shows dielectric strength of blend samples under dry conditions by using curve fitting.

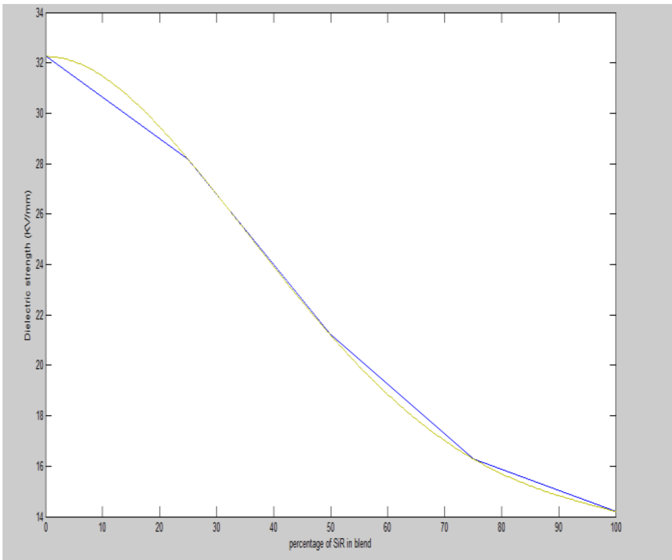

Fig 8. Curve fitting results for dielectric strength (kV/mm) of blend samples under dry condition.

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial equation as follow:

Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5

Coefficients
P1 = -4.5333e-007
P2 = 0.00012112
P3 = -0.0094207
P4 = 0.0037
P5 = 32.25

Figure 9 shows curve fitting for dielectric strength of blend samples under wet conditions. The dielectric strength decreased in wet condition as compared with those in dry condition. This is due to the degradation of samples which affected by water.

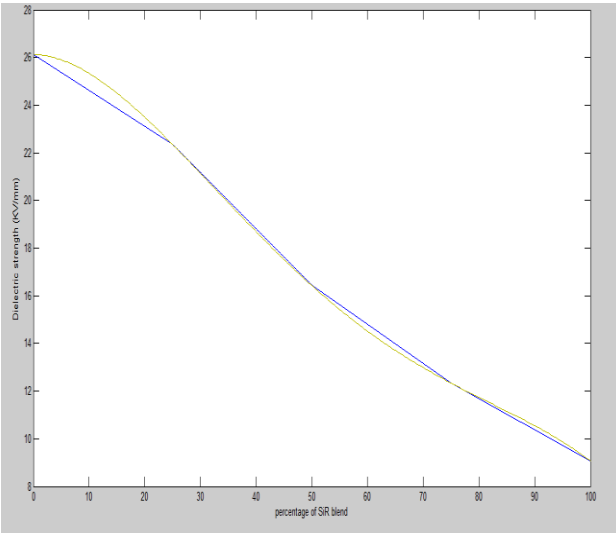

Fig 9. Curve fitting results for dielectric strength (kV/mm) of blend samples under wet condition

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial growth equation as follow:

Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5

Coefficients
P1 = -5.2907e-007
P2 = 0.0001216
P3 = -0.0085093
P4 = -0.0066
P5 = 26.13

Figure 10 shows dielectric strength (kV/mm) of blend samples under low salinity conditions by using curve fitting. As the amount of EPDM increases, the dielectric strength increases, it may be due to the cross-linked between the molecules of EPDM which is making a good bond inside the structure of EPDM.

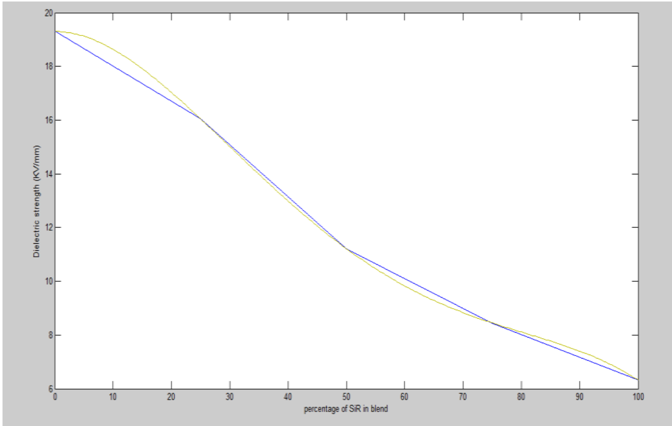

Fig 10. Dielectric strength (kV/mm) of blend samples under low salinity conditions by using curve fitting.

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial growth equation as follow:

Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5

Coefficients
P1 = -5.4187e-007
P2 = 0.00012011
P3 = -0.0078933
P4 = 0.00033333
P5 = 19.3

Figure 11 shows curve fitting for dielectric strength (kV/mm) of blend samples under high salinity conditions.

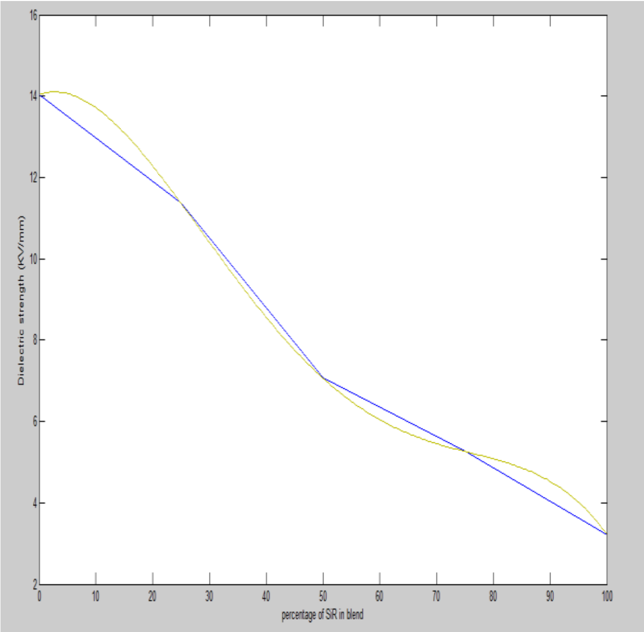

Fig 11. Dielectric strength (kV/mm) of blend samples under high salinity conditions by using curve fitting.

From the calculation of the program the best curve fitting for the data obtained can be represented by 4th degree polynomial growth equation as follow:

Y = P1*X^4 + P2*X^3+ P3*X^2 + P4*X+ P5

Coefficients
P1 = -7.3173e-007
P2 = 0.00015371
P3 = -0.0096227
P4 = 0.048733
P5 = 14.04

From fig. 6 and fig. 8 that increased proportion of silicone rubber enhances the tracking resistance, whereas increasing weight percentage of EPDM improves the dielectric strength of the blends. It may due to the surface roughness of EPDM is rougher than SiR.

IV. CONCLUSION

The main conclusions can be drawn from this work:

1- The tracking resistance time of the blend samples increase from 11 minutes for sample A to 44 minutes for sample E. It can be seen that, the tracking resistance was improved by increasing of SiR percentage in the blends.
2- EPDM has the minimum value of tracking resistance time.
3- Pure EPDM (sample A) has the maximum value of dielectric strength (32.25 kV/mm), While pure SiR (sample E) has the minimum value of dielectric strength (14.2 kV/mm).It can be seen that, the dielectric strength was improved by increasing of EPDM percentage in the blends.
4- The dielectric strength decreased in wet condition as compared with those in dry condition.
5- The exposure to salt water solution drastically affected the dielectric strength.
6- As a result of previous points, the suitable percentage can be used for blend rubber sample is 50% SiR and 50% EPDM (Sample C).

ACKNOWLEDGMENT

The authors would like to thank the staff of High Voltage Laboratory, Electrical Engineering Dept. Aswan University and Polymers and Pigments Dept., National Research Center, where most of the samples preparation and experimental work were carried out.

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