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Comparison of Ageing Deterioration of Silicone Rubber Outdoor Polymer Insulator under Salt Water Dip Wheel Test

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Abstract**—**This paper presents the experimental results on ageing deterioration of silicone rubber outdoor polymer insulator under salt water dip wheel test based on IEC 62217. In order to comparison effect of chemical contents, silicone rubber outdoor polymer insulators having same configuration and leakage distant from two manufactures were tested together continuously 30,000 test cycles. Many discharge activities were observed in during the test. After 30,000 test cycles, in spite of same configuration, differences in degree of surface aging were observed. Physical analysis such as decreasing in hydrophobicity and increasing in hardness measurement were measured on two-type tested specimen surface in order to confirm degree of surface ageing. Furthermore, chemical analysis by ATR-FTIR to diagnose the chemical change of tested specimen surface was conducted to confirm the physical analysis results.

Keywords**—**ageing of silicone rubber, salt water dip wheel test, silicone rubber polymer insulator

I. Introduction

SILICONE rubber or polydimethylsiloxane (PDMS) has been widely used to produced housing material for insulators in high voltage outdoor insulation system. Silicone rubbers have advantages of low cost, light weight, high mechanical strength, low surface tension energy and good electrical strength comparing with porcelain and glass insulators. Due to silicone rubber or PDMS having organic nature, environmental conditions are important factor for structural changing in PDMS material. In addition, electrical stress is mainly caused discharge activities to polymer insulator surface such as dry band arc and corona discharge etc. Resulting, polymer insulator surface was damaged by environmental and electrical conditions. Physical change (such as tracking) and chemical change (such as loss of hydrophobicity) were affected to ageing on polymer insulator surface [1-5].

Yu et al. [6] studied about the properties of tracking wheel test method under DC voltages such as positive DC voltage and negative DC voltage. The result of tested under DC voltage compared with the result of tested under AC voltage.

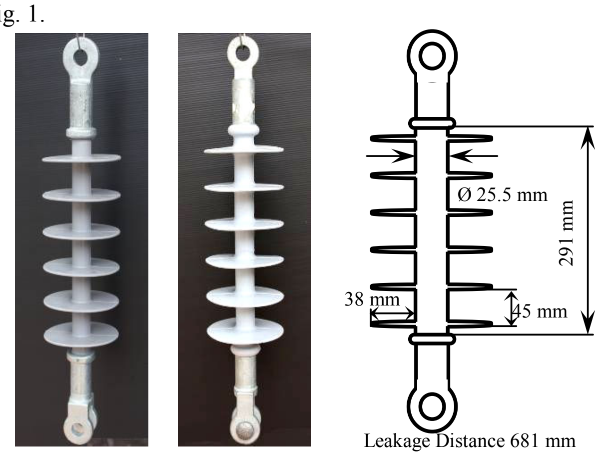
Muncivi et al. [7] used the software and hardware computer control were studied the tracking of the silicone rubber polymer insulators. The testing of silicone rubber polymer insulators were tested 181 cycles base on BS EN 62217:2006.

This paper reports the experimental study on ageing deterioration of silicone rubber outdoor polymer insulator for 22 kV distribution systems under salt water dip wheel test.

II. Test Arrangements

A. Specimen

Straight shed polymer insulators made of HTV silicone rubber with ATH (Alumina trihydrate) were used in this experimental. This type of polymer insulator is used for 22 kV distribution systems. However, amounts of chemical contents of housing material are different due to different manufactures. All specimens having same configuration and dimension were tested together under test conditions based on IEC 62217 [8]. Configuration and dimension of the specimen are illustrated in Fig. 1.



(a) Type-A (b) Type-B (c) Dimension

Fig. 1 Specimen

B. Test Method

Test methods for salt water dip wheel test were based on IEC 62217 [9]. Cyclic test was conducted continuously for 30,000 cycles. One test cycle takes 192 second and includes 4 test positions, energized, de-energized, salt water dip and de-energized, respectively. At each position, specimen remains stationary for 40 second and takes 8 second for rotate to the next position. Salt water was re-newed every week with re-

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newing time less than 1 hour. Test arrangement for dip wheel test is shown in Fig. 2 and the specimen arrangement during test is shown in Fig. 3.

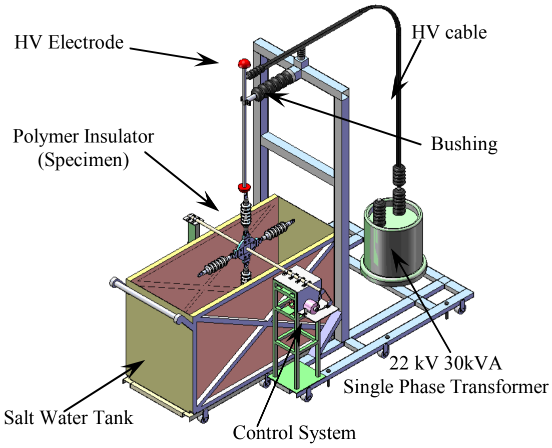


Fig. 2 Test arrangement for salt water dip wheel test

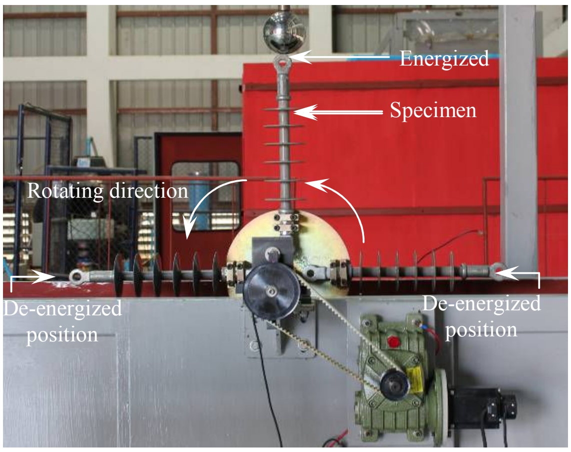


Fig. 3 Specimen arrangement during salt water dip wheel test

C. Test Condition

Test was conducted based on test conditions in IEC 62217, as illustrated in Table I. Test voltage was generated from 22 kV, 30 kVA single phase transformer.

TABLE I
TEST CONDITIONS

Voltage stress	35 V/mm (AC voltage)
NaCl content of de-ionized water	1.4 kg/m^3 ± 0.06 kg/m^3
Test duration (1 cycle = 192 second)	30,000 cycles

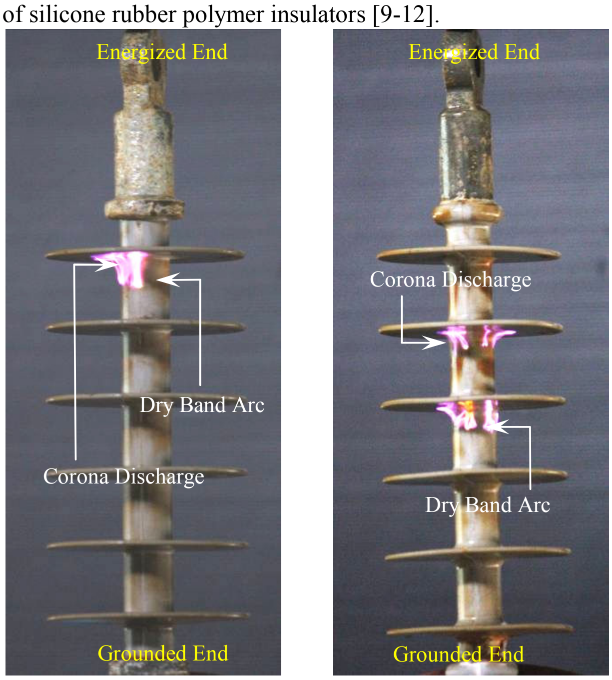
III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Degree of physical damaged was inspected by visual observation, reduction of hydrophobicity, surface contamination degree and hardness after 30,000 test cycles. In addition, any chemical changing of specimen surface was analyzed by using ATR-FTIR. The chemical analysis results were used to confirm the physical changing.

A. Visual observation

During test, visual observation was used to observe the physical changing of silicone rubber polymer insulators surface. Many discharge activities were observed during the test, dry band arc and corona discharge were often observed on the trunk surface.

As shown in Fig. 4, visible discharge activities during the test were often observed on the trunk surface for all specimens. Yellow light paths indicate dry band arcing and purple light spot indicate corona discharges. These phenomenons caused reduction of hydrophobic and ageing deterioration on surface of silicone rubber polymer insulators [9-12].



(a) Type-A (b) Type-B

Fig. 4 Visible discharge activities during salt water dip wheel test.

After 30,000 test cycles, significant changing on the specimen surface was observed on all tested specimen. Many types of surface ageing, such as erosion and tracking etc., were observed.

As shown in Fig. 5 (a), dirt was observed on both shed and trunk surfaces of tested specimen.

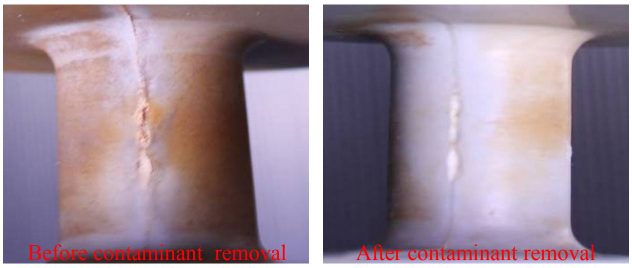
As shown in Fig. 5 (b), slightly surface tracking was observed on parting line of trunk surface near the energized end.

As shown in Fig 5 (c) and Fig. 5 (d), severely tracking was observed on the parting line of trunk surface near the grounded end. The occurrence of surface tracking on such position may due to higher electric field stress. Electrical discharges may cause surface damaged [13].

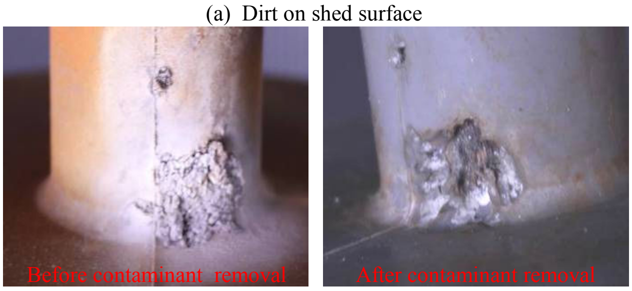
As shown in Fig. 6 (a), dirt was observed on both shed and trunk surface of type-B specimen same as type-A specimen

As shown in Fig. 6 (b) and Fig. (c), slightly surface tracking was observed on both shed and trunk surface near the energized end.As shown in Fig. 6 (d), punched of trunk near ground end was observed. The puncture was observed on the parting line of trunk.

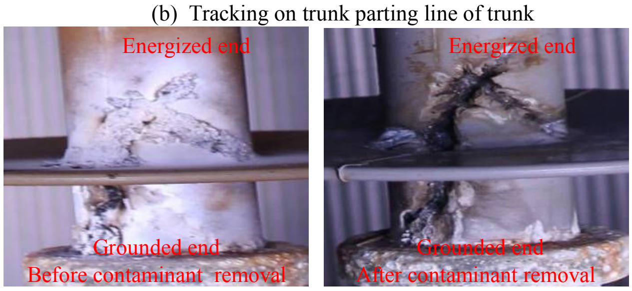
(a) Dirt on shed surface



(b) Tracking on trunk parting line of trunk



(c) Tracking on trunk

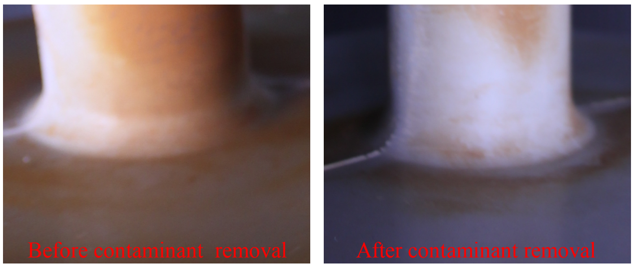


(d) Tracking on trunk

Fig. 5 Surface damaged of Type-A specimen

(a) Dirt on shed surface

(b) Tracking on shed parting line



(c) Tracking on parting line of trunk.

(d) Tracking on parting line of trunk.

Fig. 6 Surface damaged of Type-B specimens

B. Contamination Degree

Under contamination condition, contamination layer causes leakage current along the specimen surface and leakage current causes dry band. Finally, higher electric field stress over dry band causes dry band arcing. Dry band arcs cause tracking on the insulator surface. Therefore, salt deposit density (SDD) is used to identify the contamination level along the insulators surface. The formulas for SDD calculation are as follows.

$$S_a = (5.7\sigma_{20})^{1.03} \quad (1)$$

$$SDD = \frac{S_a \times V}{A} \quad (2)$$

where:

σ_{20} is the volume conductivity at temperature of 20°C (S/m)

S_a is salinity (kg/m^3)

SDD is the salt deposit density (kg/m^2)

V is the volume of the suspension (m^3)

A is the area of the cleaned surface (m^2) [14,15].

TABLE II
SDD AFTER 30,000 TEST CYCLES

SDD, mg/cm^2			
Type-A Specimen		Type-B Specimen	
No. 1	0.0205	No. 1	0.0228
No. 2	0.0178	No. 2	0.0149

As illustrated in Table II, no significant different in SDD was obtained. This may due to tested specimen having same configuration and dimension.

C. *Hydrophobicity*

By products from discharge activities such as heat and UV can cause reduction of hydrophobicity of polymer insulator surface. STRI classification guide as shown in Fig. 7, is used to specified the level of hydrophobicity for the specimens [16,17]. HC level for tested specimen was evaluated. The evaluation results are shown in Fig. 8 and are shown in Table III.

After 30,000 test cycles, reduction of hydrophobicity level on all specimens was obtained when comparing with the new specimen. As illustrated in Table III, largest reduction of hydrophobicity (HC5) was measured on trunk surface of all specimens. For shed surface, reduction of hydrophobicity level at HC3 was measured.

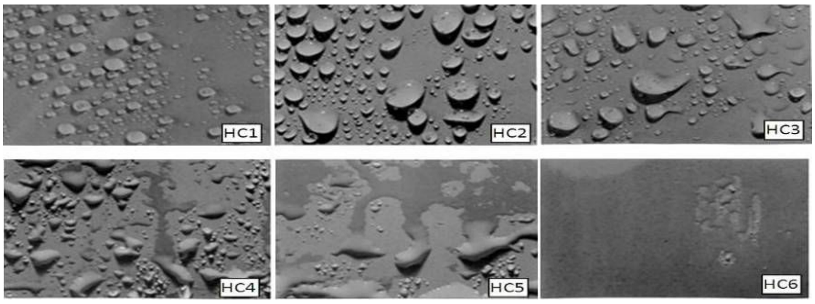
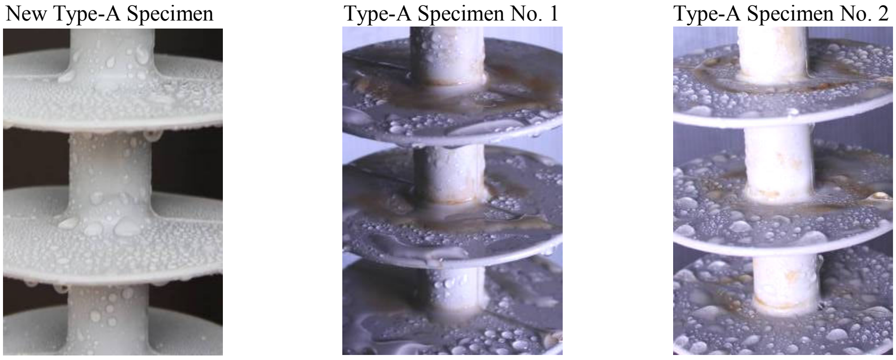


Fig. 7 Classification of hydrophobicity (HC1-HC6)[15]

New Type-A Specimen Type-A Specimen No. 1 Type-A Specimen No. 2

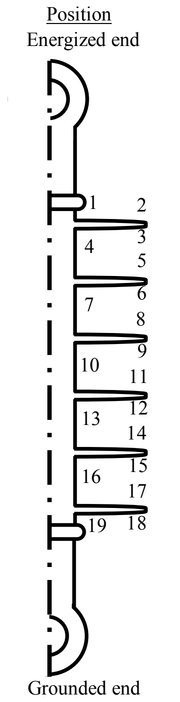


New Type-B Specimen Type-B Specimen No. 1 Type-B Specimen No. 2

Fig. 8 Comparison of reduction of hydrophobicity

TABLE III
REDUCTION OF HYDROPHOBICITY AFTER 30,000 TEST CYCLES

Position	Specimen					
	Type-A			Type-B		
	New	No. 1	No. 2	New	No. 1	No. 2
1	↑	HC3	HC5	↑	HC3	HC4
2		HC3	HC3		HC4	HC4
3		HC4	HC2		HC3	HC3
4		HC5	HC4		HC5	HC5
5		HC4	HC4		HC4	HC4
6		HC3	HC3		HC3	HC3
7		HC5	HC4		HC4	HC5
8		HC3	HC4		HC4	HC4
9		HC3	HC3		HC3	HC3
10	HC1	HC5	HC4	HC1	HC5	HC5
11		HC4	HC4		HC4	HC4
12		HC3	HC3		HC3	HC3
13		HC3	HC3		HC5	HC5
14		HC4	HC3		HC4	HC4
15		HC3	HC3		HC3	HC2
16		HC4	HC3		HC5	HC4
17		HC3	HC3		HC4	HC4
18	↓	HC4	HC3	↓	HC3	HC2
19		HC3	HC3		HC4	HC4



D. ATR-FTIR Analysis

ATR-FTIR (attenuated total reflection Fourier transform infrared spectroscopy) is chemical analysis technique for the chemical bonds changing inspection. Side chains bond ($Si-CH_3$) at wave number 1258 cm^{-1} and back bond (Si-O) at wave number 1010 cm^{-1} of silicone rubber surface were analyzed. Reduction of $Si-CH_3$ indicates side chain scission. Reduction of Si-O spectrum indicates back bond scission. An example of ATR-FTIR spectrum of trunk surface at position 10 of tested surface comparing with the new specimen surface is illustrated in Fig. 9.After 30,000 test cycles, decreasing of side chain and back bond spectrums were obtained for both types of tested specimens when comparing with the new specimen. Mostly changing of side chain and back bone bonds were measured on trunk surface when comparing with shed surface. ATR-FTIR analysis results for all position of all-type specimens are illustrated in Table IV and Table V.

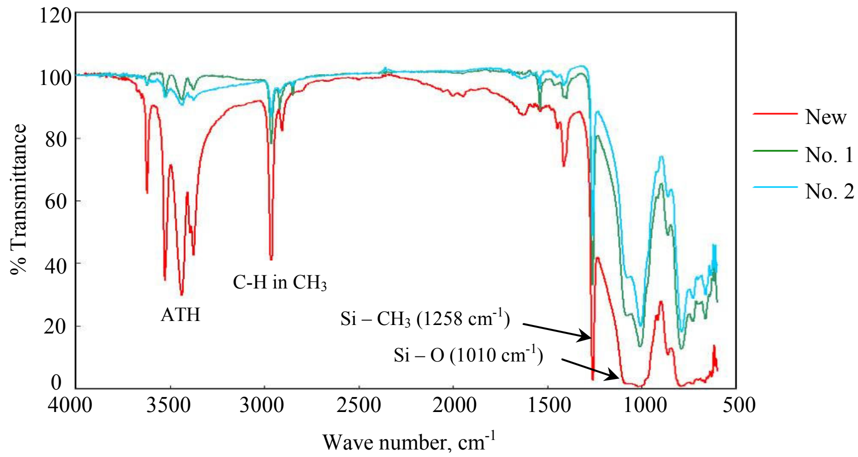
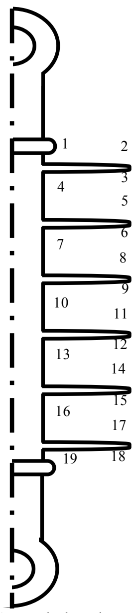


Fig. 9 ATR- FTIR spectrum of Type-A specimen at position 10

TABLE IV
TRANSMITTANCE OF SI-CH_3 BOND AFTER 30,000 TEST CYCLES

Position	Transmittance of Si-CH_3 (1258 cm^{-1}), %					
	Type-A Specimen			Type-B Specimen		
	New	No. 1	No. 2	New	No. 1	No. 2
1		49.60	53.86		22.20	36.38
2	↑	77.79	80.70	↑	77.65	80.36
3		79.11	86.18		84.99	80.37
4		59.08	41.07		13.60	30.96
5		79.03	75.34		82.39	77.35
6		82.25	88.65		88.35	70.83
7		42.75	26.59		45.43	67.78
8		85.02	88.44		78.56	77.67
9	100	83.93	84.41	100	95.17	82.42
10		68.07	51.91		36.00	66.30
11		74.26	81.95		76.66	84.61
12		82.16	88.78		81.81	80.28
13		75.60	22.14		64.19	43.66
14		83.18	97.42		85.93	73.61
15		85.75	97.43		83.07	83.43
16		69.19	49.02		71.42	70.57
17		78.77	94.55		82.76	75.57
18		73.83	91.29		73.49	70.04
19	↓	68.18	26.95	↓	37.83	21.46

Position
Energized end

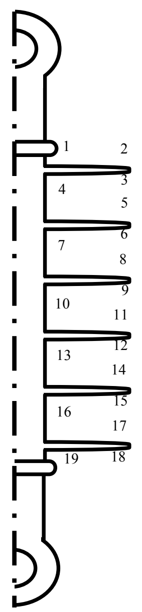


Grounded end

TABLE V
TRANSMITTANCE OF SI-O BOND AFTER 30,000 TEST CYCLES

Position	Transmittance of Si-O (1010 cm^{-1}), %					
	Type-A Specimen			Type-B Specimen		
	New	No. 1	No. 2	New	No. 1	No. 2
1		79.01	75.33		63.70	80.40
2	↑	78.81	86.04	↑	92.73	88.83
3		80.09	87.98		92.74	89.42
4		84.90	69.26		93.37	69.76
5		82.33	81.80		89.90	88.35
6		86.58	91.80		93.88	85.56
7		69.10	63.31		85.57	68.68
8		85.87	88.98		99.61	84.99
9	100	83.24	86.19	100	96.05	87.37
10		87.43	80.33		70.49	86.04
11		79.74	84.57		92.87	91.04
12		84.37	88.89		93.34	84.12
13		83.54	57.47		90.28	80.18
14		91.51	96.44		92.07	92.94
15		88.26	96.41		94.02	86.74
16		85.93	81.23		94.20	85.82
17		84.02	94.35		91.73	89.73
18		78.69	91.22		92.90	87.93
19	↓	87.52	40.87	↓	79.43	52.01

Position
Energized end



Grounded end

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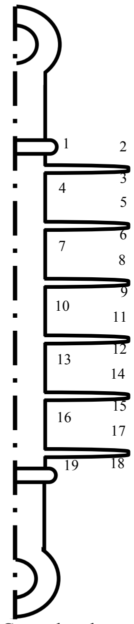
E. Hardness Measurement Results

In this study, hardness was measured based on ISO 686-Shore hardness [18] by using Shore durometer. Measurement results of hardness are shown in Table VI. As shown in Table VI, increasing in hardness of all tested specimens was obtained when comparing with new specimen. Increasing in surface hardness indicate the occurrence of oxidation crosslink of polydymethylsiloxane matrix. More increasing in hardness was measured on specimen type–A when comparing specimen type-B. In addition, increasing of surface hardness confirmed the chemical reaction in the specimen surface.

TABLE VI
HARDNESS OF SPECIMEN AFTER 30,000 TEST CYCLES

Position	Shore 's hardness scale					
	Type-A Specimen			Type-B Specimen		
	New	No. 1	No. 2	New	No. 1	No. 2
1	↑	51.68	52.80	↑	52.24	55.20
2		61.36	63.04		56.96	56.88
3		51.52	63.28		50.80	53.36
4		42.16	50.40		49.76	48.48
5		53.48	63.12		53.04	54.32
6		62.56	63.52		57.76	56.40
7		42.56	47.92		50.32	48.24
8		61.84	61.84		57.84	56.64
9		61.92	62.72		51.28	52.40
10	38.08	42.40	51.28	43.36	50.32	48.24
11		62.40	62.80		54.72	55.60
12		62.48	62.96		58.16	55.36
13		43.28	46.00		74.2	46.96
14		62.16	62.80		58.64	57.04
15		61.76	62.64		54.16	55.20
16		47.12	46.64		49.04	54.56
17		62.96	63.20		56.96	54.56
18		63.20	62.88		53.04	56.80
19	↓	54.24	52.64	↓	54.16	50.64

Position
Energized end



Ground end

IV. CONCLUSION

Silicone rubber polymer insulators having same configurations and dimensions from two manufacturers were tested under salt water dip wheel test for 30,000 cycles and were subjected to electric field at 35 V ac /mm. Surface tracking and trunk puncture were observed on both type specimen surfaces after 30,000 test cycles. However, severely tracking was observed on specimen type–A comparing with specimen type– B. Physical analysis results and chemical analysis results confirmed the experimental results as well.

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