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Leakage and Flashover Current in the provided Silicon Rubber Coal Dust Pollution (Fly Ash)

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Abstract: This study investigates the impact of coal dust (fly ash) pollutants on leakage and flashover currents in RTV 497 silicone rubber. The research examines variations in impurity conditioning over 1, 2, and 3 days, along with samples without conditioning. Silicone rubber samples, each 1 mm thick and measuring 50 x 25 mm, were prepared and attached to a leaf-like electrode system designed using the SketchUp application. Five samples were used for each conditioning variation. The samples were tested using an Aluminum Tape electrode system with a 5 mm gap between electrodes. To measure the leakage current, voltages of 220 V, 500 V, and 1000 V were applied for 1 minute each. Subsequently, the voltage was increased gradually until flashover occurred. The findings highlight the significant influence of coal dust pollutants on the electrical performance of silicone rubber insulators. The increase in leakage current and the reduction in flashover voltage underscore the need for effective pollution management strategies in industrial environments. This research provides crucial insights into the degradation mechanisms and potential mitigation approaches for maintaining the reliability of power systems exposed to environmental pollutants.

Keywords: Silicone Rubber, Leaf Like Sample, Contaminants, Coal Dust, Leakage Current

1. Introduction

Distribution of electric power systems requires good insulating materials thus they can distribute electricity properly. A material that can dampen and protect parts that conduct electricity is polymer insulating material [1][2]. Polymer materials are one of the types of insulation used in medium voltage distribution lines. Polymer-insulating materials that are widely used include Silicone Rubber (SiR) which is used as insulation in power cables and post-insulators in medium voltage systems [3][4]. Silicone rubber (SiR) is one of the materials used as an insulating material since it has the advantage of holding water (hydrophobic), heat resistance, natural aging resistance, and moisture resistance. This means that SiR has advantages in terms of retaining water when the air is humid, does not form droplets or layers of water on the surface of the material which can cause leakage currents, and has better performance than ceramic insulators or glass insulators in terms of preventing flashover. The hydrophobic properties of Silicone Rubber (SiR) can be reduced, partly due to exposure to pollutants which can accelerate the aging process of insulators [5][6].

In distributing high-voltage electric power, reliable equipment is needed. One of the common problems that arise in this process is insulation failure, especially liquid insulation and air insulation. Insulation functions to separate electrical conductors that have different voltages, thereby preventing jumps in electric current. However, if the electric field applied to the dielectric material exceeds its capacity limit, the insulation can experience a breakdown voltage phenomenon, causing damage to electrical equipment and disrupting the continuity of the working system. This is caused by two main factors, namely excessive voltage and thermal heating caused by heat energy produced by electric current. The heat generated by the electric current can increase the temperature of the insulation above its working threshold. If this heating continues continuously, the insulation will experience degradation and potential insulation failure which can cause breakdown voltage phenomena. The use of silicone rubber insulating material in industrial or mining areas can cause coal dust to stick to the surface of the insulators in the electric power transmission and distribution system for a long time, which can affect the performance of the insulation system which can ultimately cause insulation failure[7]. Dirt or pollutants on the insulator surface can facilitate the occurrence of leakage currents on the insulation surface which can increase surface conductivity, and leakage currents on the surface of the insulating material and cause flashover. Meanwhile, silicone rubber (SiR) is widely used as an insulating material because it has the advantage of retaining water (hydrophobic), meaning that in humid air conditions water droplets or layers form on the surface of the material thus it can create current leaks and can be better at inhibiting flashover than ceramic or glass insulators. The main cause of insulator surface damage is leakage current, which causes flashover and insulator damage over time [8][9]. In this research, leakage current and flashover voltage testing with silicone rubber (SiR) insulating material was carried out to study and measure leakage current and flashover voltage with a predetermined size of silicone rubber. The findings reveal how coal dust pollutants have a major impact on silicone rubber insulator's electrical performance, in terms of leakage current. Effective pollution control methods are essential in industrial settings, as seen by the rise in leakage current and the decline in flashover voltage. To preserve the reliance on power systems exposed to environmental contaminants, this research offers vital insights into the mechanisms of deterioration and possible mitigating strategies.

2. Material and Methods

The experimental procedure for this study is systematically illustrated in the flowchart in Figure 1. It begins with the preparation of samples, which includes the procurement of materials and the creation of silicone rubber sheets by mixing RTV silicone rubber with the hardener. Following the mixing and casting process, the silicone rubber sheets are allowed to dry completely. Once dried, the best-quality samples are selected for further testing.

The next step involves conditioning the selected samples. These samples are exposed to coal dust (fly ash) pollutants in a conditioning chamber. Following conditioning, the samples are prepared for testing by arranging aluminum tape electrodes.

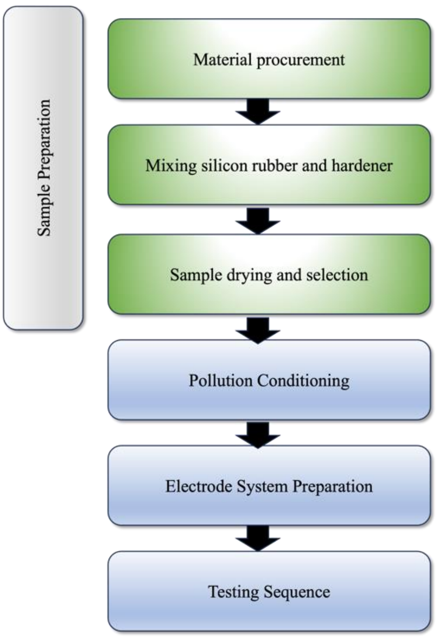

Figure 1. Experimental flowchart

The last step is testing phase involves applying voltages sequentially to the samples. Each voltage is maintained for 1 minute to measure the leakage current. After the initial measurements, the voltage is gradually increased until flashover occurs, and the corresponding flashover voltage is recorded.

2.1. *Materials*

The materials used are silicone rubber RTV-497 and catalyst. First, weigh the material using a digital scale with a sensitivity of 0.001 gr for accuracy and precision. Then pour it into a cup, add the catalyst as a hardener in a ratio of 20:1, and stir using an aluminum spoon for 3 minutes. Then proceed with the process of removing air bubbles using a vacuum pump. The liquid that has been vacuumed is poured into a mold made of glass and then the silicone rubber is allowed to dry for 24 hours (Figure 2).

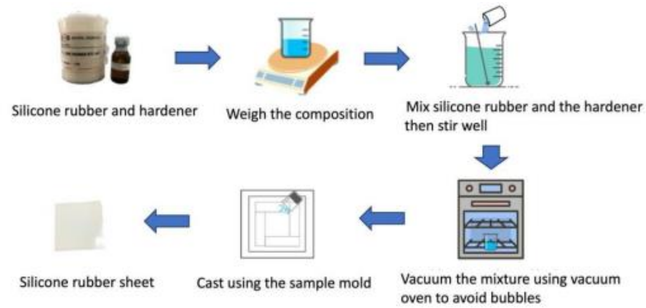

Figure 2. Stages of making test samples

2.2. *Methods*

2.2.1. *Sample collection and preparation*

The electrode arrangement in this test is based on a leaf-like sample model, aluminum tape is used as an electrode with a system of 50 mm and a width of 50 mm, glued to the silicone rubber test sample with a gap of 5 mm. This electrode system is used since this electrode shape is the easiest form to measure leakage current and flashover voltage on the silicone rubber surface, it is shaped like a leaf thus current can flow on the insulator surface, namely from the conductor to the ground (Figure 3 and Figure 4).

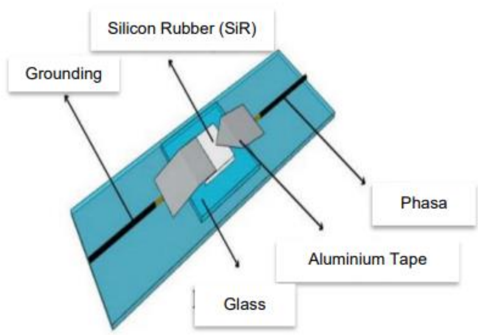

Figure 3. Electrode design system

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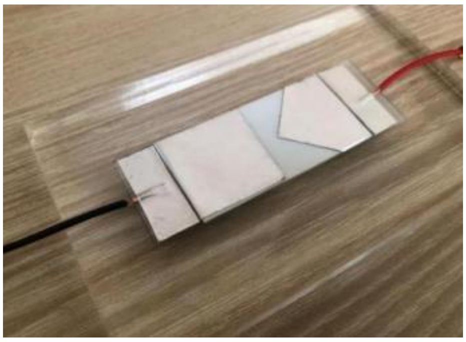

Figure 4. Electrode system used in research

2.3. Coal Dust Pollutant Conditioning

After the sample collection, it was treated with 1 wt% of the coal dust impurity (fly ash) mixed with 5 ml of water. Then spraying coal dust onto the surface of the insulation and left until the dust settled, with variations for conditioning time of 1, 2, 3 days, and without conditioning. Sample conditioning was carried out in the conditioned chamber which dimensions 28 x 21 x 10 cm (Figure 5). After the conditioning process, the samples were ready for testing.

Figure 5. Coal Dust Pollutant Conditioning Box (Fly Ash)

2.4. Test Sequence

Leakage current and flashover testing on silicone rubber insulating material means the leakage current will be seen on the surface of the sample and then the voltage will be increased until flashover occurs on the silicone rubber sample. The testing used a 220 volt with a frequency of 50 Hz. Then connected to a step-up transformer to increase the voltage, then from the transformer it is connected to a high resistance which functions is to withstand excessive current thus as not to damage the components in the circuit, from the high resistance it is connected again to the two components, which is first connected to the electrode system, then from the electrode system it passes through a Pearson current monitor to measure the current flows, from the Pearson current monitor connected to channel b of the picoscope.

Then the second is connected to a high voltage probe which functions to measure the existing voltage, from the high voltage probe it is connected to channel a picoscope, after connecting it to the picoscope which functions to convert voltage and current into the final AC waveform connected to the PC to display the measured data results (Figure 6).

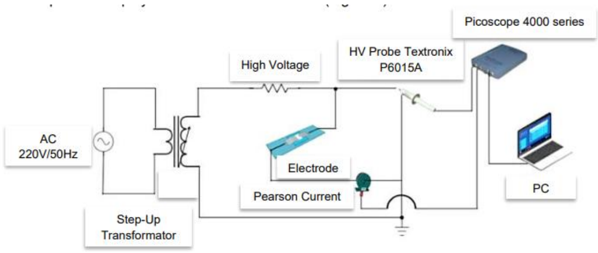

Figure 6. Current measurement test circuit leak and flashover

3. Results and Discussion

The research object used is solid insulating material Silicone Rubber RTV-497 which is exposed to impurities in the form of coal dust or Fly Ash. Variations in the duration of impurity conditioning are 1, 2, 3 days, and without conditioning, with 5 samples each for each variation of conditioning carried out (Table 1). To determine the value of the leakage current that passes through the surface of the Silicone Rubber, voltages of 220 V, 500 V, and 1000 V are applied, left for 1 minute for each voltage application variation to read the value of the current flowing on the sample surface, then the voltage is increased slowly until flashover occurs.

For the samples conditioned for 1 day, the test began by applying a voltage of 220 V for 1 minute to record the leakage current. After recording the current, the voltage was increased to 500 V and then to 1000 V, each time maintaining the voltage for 1 minute and recording the corresponding leakage current. After these initial measurements, the voltage was gradually increased until flashover occurred.

This procedure was identically followed for samples conditioned for 2 and 3 days. The aim was to compare how the duration of exposure to coal dust affected the electrical properties of the silicone rubber. The expectation was that longer conditioning times would result in higher leakage currents and lower flashover voltages due to the increased pollutant deposition on the sample surfaces.

The systematic approach ensured consistency and reliability in measuring the effects of coal dust pollution on silicone rubber insulators. The results from these tests provided critical insights into how environmental pollutants impact the performance and durability of insulating materials used in electrical systems.

Figure 7 illustrates the relationship between the conditioning time of silicone rubber samples and the resulting leakage current under different applied voltages. The data indicates a trend of increasing leakage current with extended conditioning times (0, 1, 2, and 3 days).

Table 1. Table of leakage current values at each conditioning time

Conditioning	Average Leakage Current (mA)		
	Voltage 220 V	Voltage 500 V	Voltage 1000 V
Without Conditioning	34,53	34,64	34,70
1 day	34,69	34,72	34,90
2 days	34,81	34,89	34,97
3 days	35,09	35,16	35,29

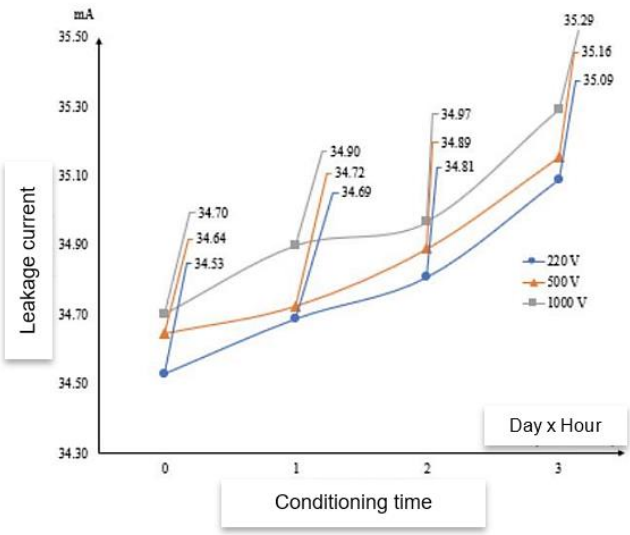

Figure 7. Leakage current values with time

For an applied voltage of 220 V, the leakage current increases by 0.5% after 1 day of conditioning, 0.8% after 2 days, and 1.6% after 3 days compared to the unconditioned sample. Similarly, when a voltage of 500 V is applied, the leakage current rises by 0.2% after 1 day of conditioning, 0.7% after 2 days, and 1.5% after 3 days. For an applied voltage of 1000 V, the leakage current increases by 0.6% after 1 day, 0.8% after 2 days, and 1.7% after 3 days compared to the unconditioned sample.

The observed increase in leakage current is attributed to the contaminant layers on the surface of the silicone rubber insulators. As current flows from the conductor to the ground, these contaminant layers facilitate a higher leakage current across the surface. The pollutants, primarily coal dust (fly ash), adhere to the insulator surface during the conditioning period. Additionally, other contaminants may attach to the samples during the electrode attachment process, further influencing the leakage current.

These findings highlight the significant impact of pollutant accumulation on the electrical performance of silicone rubber insulators. The increasing leakage current with extended conditioning times underscores the need for effective pollution management strategies to maintain the reliability and performance of insulating materials in polluted environments.

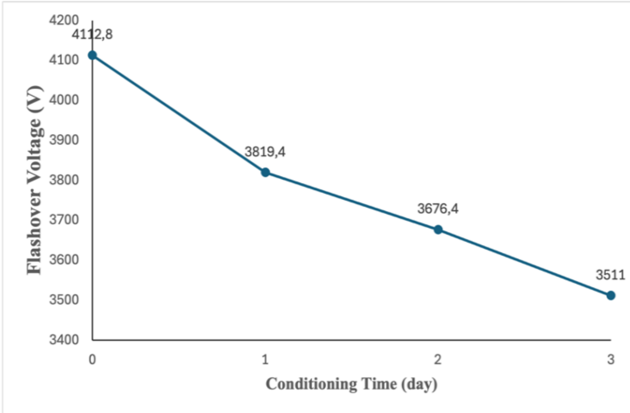

Figure 8. Flashover voltage values with time

In Figure 8, the flashover test results on silicone rubber with varying conditioning times of 0, 1, 2, and 3 days show a clear trend of decreasing flashover voltage values. Specifically, a conditioning time of 1 day resulted in a 7.1% reduction in flashover stress compared to the sample without conditioning. With a conditioning time of 2 days, the flashover stress value decreased by 11%, and after 3 days of conditioning, the reduction was 15% compared to the unconditioned samples.

Flashover on silicone rubber insulation surfaces is influenced by both the applied voltage and the pollutants accumulated on the surface. Dust contaminants, such as coal dust (fly ash), tend to settle and adhere to insulators, significantly contributing to flashover and failure. This accumulation increases surface conductivity, thereby lowering the flashover voltage threshold [10].

The longer the conditioning period, the more pronounced the degradation of the silicone rubber insulators, leading to quicker flashover occurrences. This is corroborated by the observed increase in leakage current with extended pollution conditioning times. The increased leakage current accelerates the onset of flashovers due to the enhanced pollution coating on the insulator surface. These findings highlight the critical impact of environmental pollutants on the performance and reliability of silicone rubber insulators, underscoring the need for effective pollution management and maintenance strategies to mitigate these effects [11][12].

4. Conclusion

The study on leakage current and flashover in silicone rubber treated with coal dust (fly ash) pollutants reveals several key findings. Firstly, the conditioning duration significantly impacts the test results. Specifically, conditioning for 1-, 2-, and 3-days results in a percentage increase in leakage current values by 0.2%, 0.7%, and 1.5%, respectively, compared to no conditioning. This increase is attributed to the prolonged exposure to coal dust impurities, which enhances surface conductivity and reduces the flashover voltage. Secondly, the applied voltage levels directly affect the leakage current on the silicone rubber surface. Higher voltages correspond to higher leakage currents, and longer conditioning times further decrease the flashover voltage. This is due to the reduction in surface resistance caused by the applied voltage. These findings underscore the importance of considering both conditioning duration and voltage levels in managing the electrical performance of silicone rubber insulators in polluted environments.

Building on the findings of this study, future research should explore several avenues to further understand and mitigate the impact of coal dust (fly ash) pollutants on silicone rubber insulators. Firstly, investigations could focus on the development of advanced materials or coatings that enhance the hydrophobicity and pollution resistance of silicone rubber. Additionally, long-term field studies are necessary to validate laboratory results and assess the real-world performance of these insulators in various environmental conditions. Another promising direction is the application of novel cleaning and maintenance strategies to minimize pollutant accumulation on insulator surfaces.

References

[1] M. S. Wakhidin, "Effects of Aging on Insulation Performance of Silicone Rubber Polymeric Insulators in Various Conditions," *J. Tek.*, pp. 1–6, 2019.

[2] L. Mu, B. Wang, J. Hao, Z. Fang, and Y. Wang, "Study on material and mechanical characteristics of silicone rubber shed of field-aged 110 kV composite insulators," *Sci. Rep.*, vol. 13, no. 1, pp. 1–12, 2023, doi: 10.1038/s41598-023-35701-8.

[3] M. T. Nazir, B. T. Phung, and M. Hoffman, "Performance of silicone rubber composites with SiO2 micro/nano-filler under AC corona discharge," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 23, no. 5, pp. 2804–2815, Oct. 2016, doi: 10.1109/TDEI.2016.7736840.

[4] J. D. Samakosh and M. Mirzaie, "Experimental-based models for predicting the flashover voltage of polluted sir insulators using leakage current characteristics," *IET Sci. Meas. Technol.*, vol. 14, no. 10, pp. 943–952, 2020, doi: 10.1049/iet-smt.2020.0021.

[5] N. Dhahbi-Megriche and A. Beroual, "Time-frequency analyses of leakage current waveforms of high voltage insulators in uniform and non-uniform polluted conditions," *IET Sci. Meas. Technol.*, vol. 9, no. 8, pp. 945–954, 2015, doi: 10.1049/iet-smt.2015.0116.

[6] A. A. Salem *et al.*, "Proposal of a dynamic numerical approach in predicting flashover critical voltage," *Int. J. Power Electron. Drive Syst.*, vol. 10, no. 2, pp. 602–610, 2019, doi: 10.11591/ijpeds.v10.i2.pp602-610.

[7] I. M. D. Harinata, J. Ilham, and T. I. Yusuf, "Karakteristik Tegangan Tembus Isolasi Cair dan Isolasi Udara pada Beberapa Perubahan Suhu dan Diameter Elektroda," *J. Tek.*, vol. 17, no. 1, pp. 1–18, 2019, doi: 10.37031/jt.v17i1.39.

[8] M. T. Nazir, B. T. Phung, S. Yu, Y. Zhang, and S. Li, "Tracking, erosion and thermal distribution of micro-AlN + nano-SiO2 co-filled silicone rubber for high-voltage outdoor insulation," *High Volt.*, vol. 3, no. 4, pp. 289–294, 2018, doi: 10.1049/hve.2018.5033.

[9] A. A. Salem *et al.*, "Pollution Flashover Voltage of Transmission Line Insulators: Systematic Review of Experimental Works," *IEEE Access*, vol. 10, pp. 10416–10444, 2022, doi: 10.1109/ACCESS.2022.3143534.

[10] M. Jiang, J. Guo, Y. Jiang, L. Li, and M. Lu, "Dust contamination on surface of transmission line insulators in air-polluted regions in China: statistical characteristics, adhesion mechanism, and environmental impact factors," *Environ. Sci. Pollut. Res.*, vol. 27, no. 19, pp. 23643–23654, 2020, doi: 10.1007/s11356-020-08692-6.

[11] H. R. Sezavar, N. Fahimi, and A. A. Shayegani-Akmal, "An Improved Dynamic Multi-Arcs Modeling Approach for Pollution Flashover of Silicone Rubber Insulator," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 29, no. 1, pp. 77–85, 2022, doi: 10.1109/TDEI.2022.3146531.

[12] Arshad, A. Nekahi, S. G. McMeekin, and M. Farzaneh, "Effect of pollution severity and dry band location on the flashover characteristics of silicone rubber surfaces," *Electr. Eng.*, vol. 99, no. 3, pp. 1053–1063, 2017, doi: 10.1007/s00202-016-0473-3.