POWDERED INSULATORS FOR HIGH VOLTAGE APPLICATIONS

BRANDON DE GREEF

University of Pretoria

Abbreviations

High Voltage = HV

Breakdown Voltage = BV

Abstract

We present the innovative idea of using powdered metal oxides and hydroxides as an electrical insulators in high-voltage equipment that would need to be accessed for repair, upgrade or change in any way. In this paper, we describe the development of a testing methodology for powdered insulators as well as the results of testing MgO, $CaCO_3$, $NaHCO_3$ and other powders in order to determine their breakdown voltage, which we found to be 2.2 kV / mm ±0.15, 1.82 kV / mm ±0.1 and 0.83 kV / mm ±0.09, respectively.

Introduction

High voltages are required for the efficient distribution of electricity. Therefore, the use of electrical insulators is very important and much research has already been done on many liquid, gas and solid insulators. Electrical insulation is very important being used everywhere where there is electricity from phones, computers, microwaves, fly zappers, transformers and more. Without them most things won't work and we will all be in danger of electrocution. Electrical insulators are materials that have very few free electrons, hence having a higher resistance[2]. Due to dielectric breakdown, all electrical insulators become conductive at high enough electric fields, for instance polyvinyl chloride[3], used as an insulator on most wires, breaks down under an AC electric field of 20 kV/mm [8] AC.

Insulators used in high voltage (HV) equipment normally consists of materials like transformer oils, epoxies, silicones, and sulphur hexafluoride gas of which most of these are non-biodegradable, harmful and expensive. These can also be very difficult to recycle, since they can not decompose, or release toxic fumes when burnt. For example, sulphur hexafluoride costs approximately 743 USD per kg [9] while also being a strong greenhouse gas. 1 kg of sulphur hexafluoride is equilivant to 23 500 kg of CO_2 when it comes to greenhouse gasses. It also forms even more toxic products when under electrical stress . High voltage transformer oil, such as phenyl silicone oil, can cost around 7 USD per kg. Phenyl silicone oil is relatively safe but in high enough concentrations can easily lead to death due to raspatory failure [9].

Several metal oxides and hydroxides were tested like magnesium oxide, magnesium dioxide and calcium oxide as well as other available compounds. Two sodium salts were also tested, namely $NaHCO_3$ (sodium bicarbonate) which when decomposes releases CO_3,H_2O and Na_2CO_3 at 80°C This was tested mainly to see how sodium salts shall react, possibly decomposing into water making it more electrically conductive [11].

This research aims to find an insulator in the form of a powder that can be slightly compacted into electrical devices to achieve an adequate electrical insulation while being more environmentally friendly, easier to remove and hence perform maintenance more easily and safer to work with compared to solidified epoxy, resin or oil.

Procedure

Some initial experimentation was required to find a suitable method to measure the dielectric breakdown.

A schematic drawing of the measuring jig is shown in Figure 1. It consisted of two electrodes made of brass placed in an acrylic tube. The acrylic tube serves the purpose to show the arc forming, and also to separate the electrodes. The distance between the two electrodes were 10.1 ±0.2mm .

The powdered insulator was put between two electrodes. The powder was then slightly compressed after which the test jig was connected to the rest of the circuit.

The general setup can be seen in Figure 2. The large orange box being the high voltage transformer and on the small table to the left is the test jig, where the test samples were placed.

Figure 1

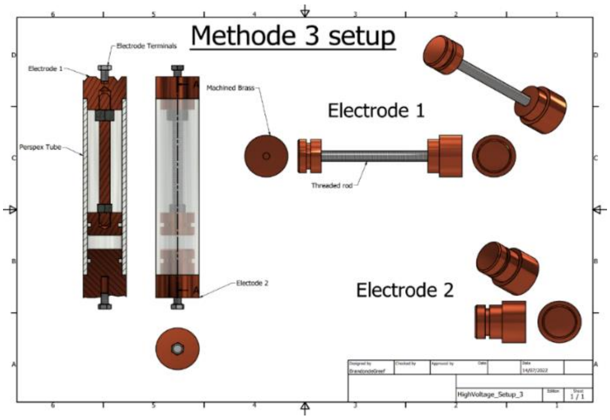

Figure 2 : Diagram showing the testing setup used

The setup consisted of a large variac (a variable transformer) and a large HV transformer that multiplies the input voltage by 217. The output voltage was measured with a high voltage probe and multimeter. A current limiting resistor was placed in series with the output of the HV transformer to protect the test setup by limiting the maximum current.

The following insulators were investigated:

- MgO (Magnesium oxide)
- MgO_2 (Magnesium dioxide)
- CaO (Calcium oxide)
- $CaCO_3$ (Calcium carbonate)
- $CaSO_4$ (Calcium sulphate)

- NaCl (Sodium chloride)
- $NaHCO_3$ (Sodium bicarbonate)

Results

All the compounds tested, performed better than the base test, which was air. The best preforming compound being MgO, Magnesium Oxide, which had a breakdown voltage nearly twice that air.

Discussion and Conclusion

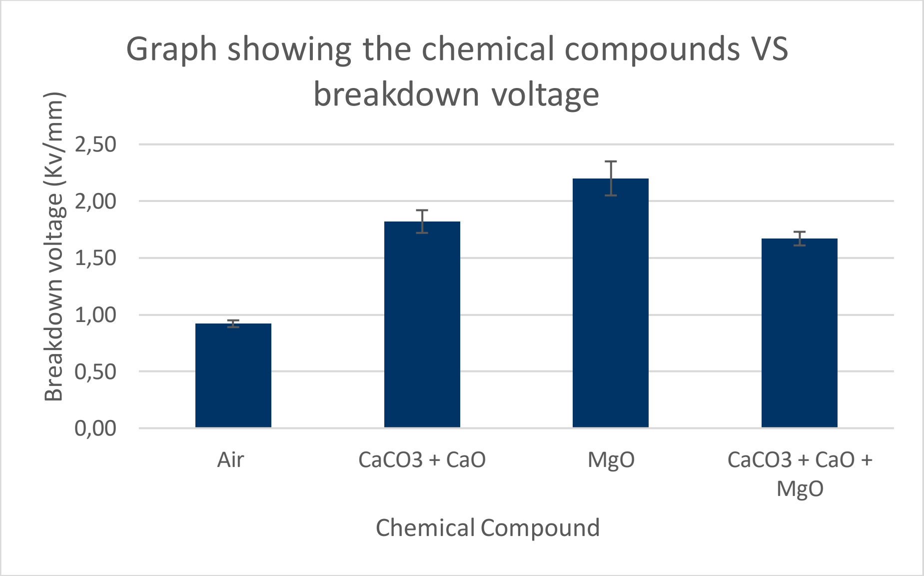

Figure 3: Breakdown voltage of the different chemical compounds tested.

The typical literature value of the BV of dry air is around 3 kV/mm. In all of the tests that were done, none of the BV values of air were close to 3 kV/mm. This could be due to many factors, such as the humidity,[10] which tends to lower the breakdown voltage and temperature also lowers the breakdown voltage [1] , barometric pressure and air quality (number of dust / particulates in the air), greatly affected the BV of air by reducing it to as low as 0.92 ± 0.03 kV/mm. This indicates that all of the powders that were tested also had a different BV depending on the atmospheric conditions. One of these relates to Paschen's law, which states "as pressure decreases so will the BV decrease at a set distance between the electrodes". This is clear because the measured pressure during the tests was around 832.0 - 842.3 ± 0.5 mBar, well below the sea level atmospheric pressure of 1013.2 ± 0.5 mBar, resulting in a lower BV for air. It is therefore expected that the BV for air would be proportionally lower.

Other factors that influenced the BV of many of the compounds was the amount of pressure applied to the setup when the powder was being loaded, and the particle size of the compounds [7], neither of which were measured due to lack of equipment. Both of these factors were part of a large problem of how the particles of powder were being moved or removed from the setup due to the strong electrostatic fields and some ion drag force [6]. These forces moved the particles of the powders around, much of it being expelled from the setup, this results in an air gap between the electrodes. This could also be causing micro cracks and, with the particles being thrown into the air, this decreases the air's BV resulting in those powders having a lower BV than air due to the powders moving, transferring charge and initiating an arc.

The air being moved is caused mostly by the ionic wind [6] by the high voltage corona discharge. These flow speeds are very low, but is enough to cause movement of the air. The particles of powder also are affected by static charge which is induced by the high voltage, as well as the particles from the smaple which can easily store and carry this charge, attracting them to the electrodes. This in return caused the surrounding air to have a breakdown voltage lower than normal.

Due to all of the aforementioned factors, this resulted in the surrounding air and any uncompacted powder to decrease their BV resulting in an early failure of the sample or a flash over around the setup. This could be improved upon by using a cleaner work area and better designed setup.

Procedure three had the main purpose of moving the input terminals to be as far apart as possible to remove the chance of the air breaking down around it. This worked but resulted in some odd results, such as the BV of air being lower as previously stated, this could indicate that the measured BV values of the powders could be much higher than what was measured. Overall, there were no flash overs, and the results were slightly higher, it was also possible to accurately measure the MgO and MgO_2 with this setup, where previously these two Mg compounds could not be compressed sufficiently due them being incredibly fine.

It can be seen that powdered insulators for HV devices are possible, only if the powders are contained, and have been slightly compacted to stop any movement particles resulting in the insulation breaking down.

Based on the properties of these powders it indicates that powdered compounds can be a danger if used incorrectly, such as incorrect containment and not being compacted enough. Other than that, powdered insulators are feasible, mainly for large production, consumer goods such as electric fly-swatters, hand held tasers and ozone generators.

If the non-biodegradable insulation is replaced with one of these powdered insulators, it would allow for easier repair of these goods when they break, and when they are disposed of, they will cause less waste, and will not poison the environment nor humans.

Some of the powders, such as MgO and $CaCO_3$, also have great fire-resistant properties, being used as flame retardants, and, $CaCO_3$, being a flame-retardant when it decomposes into CO_2 if it is heated to above 840 °C.

This is one of the reasons some of the powders were mixed. MgO was very “soft” and “fluffy” making it very difficult to compact to any reasonable degree, hence the mixing of it with $CaCO_3$ which acted as more of a chalk substance and when compacted it held its shape. Ultimately, the insulator with the best properties was MgO. This is not unexpected, as MgO has a high BV in its solid ceramic form.

Limitations and Error analysis

- Human error:
    - This was due reaction time needed to detect that the sample has broken down and to stop turning the auto transformer.
- Multimeter response time:
    - The multimeter used was relatively slow to respond to a voltage change.
- Weather:
    - The temperature, humidity and pressure constantly changing also had a significant, unmeasurable effect on the readings.
- Electrode separation distance:
    - Getting the same distance apart each electrode is difficult to keep the same between tests due to the powder getting between surfaces.
- Environmental conditions:
    - The extra amount of dust caused by the powder, and the change between tests resulted in significant cross contamination.
- Compactness of powders:
    - The force used to compact the powders could not be measured due to a lack of equipment.
- Size of powder particles:

The particle sizes changed drastically between each compound, some were unable to be ground down further with available equipment, and the particle size couldn’t be measured for equal comparison

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