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Experimental Investigation of the Electrical Resistivity of Cement Dust

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Authors' contributions

This work was carried out in collaboration among all authors. Author SAO managed the analyses of the study and interpreted results. Author JAS conceptualized and supervised the study. Author OAA performed the statistical analysis and wrote the first draft of the manuscript. Author MAO wrote the protocol and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Electrical resistivity is one of the important particle–based factors influencing the performance of an Electrostatic Precipitator (ESP), a particulate control device commonly employed in most cement industries in Nigeria. Therefore, this study investigated the electrical resistivity of Cement Kiln Dust (CKD) across nine locally-operated cement manufacturing plants in Nigeria with the aim of tracing causes of performance problems associated with the ESP used for dust control in the plants. Samples of CKD were collected from the ESPs of these plants and tested for their resistance using the two probe method. The measured electrical resistivities were in the range of 10^8 – 10^{11} Ω·cm and showed strong dependence on temperature and slight variation with particle size. The CKD's resistivity increases as temperature rises from ambient to about 250℃ and declines as temperature rises above 300℃; Nevertheless, the resistivities are adaptable for efficient ESP performance in the collection of cement dust.

Keywords: Cement kiln dust; electrostatic precipitator; Nigeria; particulates; resistivity.

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1. INTRODUCTION

Electrostatic precipitator (ESP) is an important dust control device which has found acceptability in most particulate-generating industries, the commonest being thermal power plants, sinter plants, and the cement industries. However, the collection efficiency of an ESP is influenced by a number of factors, and some of these factors relate to the nature of the particles while others are dependent on the fluid from which the particles are to be removed. Among other particle-based variables, a core characteristic of particulates that affects their behaviour in an ESP is the electrical resistivity [1,2].

Electrical resistivity is the resistance to charge transfer by a substance. It is a basic property that defines how well a material conducts current [3] and it is measured with the unit ohm-metre (Ω·m). It is unarguably the most important particle-based parameter that affects the collection efficiency of an ESP because the resistivity of a dust greatly depends on other particle-based factors including size distribution, chemical composition, and surface properties of the particle [4,5]. Electrical resistivity holds much influence on electrostatic precipitator, both as a design parameter and as a performance variable [6].

Ahn, et al. [7] and Sretenovic (University of Toronto, USA, Unpublished results) identified the operational effects of electrical resistivity on ESP to include influencing the rate and magnitude of particle charging, and determining the strength of adhesion between the particles and the collecting electrode.

Beachler and Jahnke [8] classified dust resistivity values roughly into three groups: Low resistivity, Normal resistivity and High resistivity. Value less than 10^4 Ω·cm falls in the Low bracket; Normal resistivity are those in the range of 10^4 and 10^{10} Ω·cm; while a value greater than 10^{10} Ω·cm is a high resistivity. This classification agrees is also supported by recent study [1]. Albeit, the electrical resistivity of particulates must fall within the normal range in order to guarantee efficient performance of an ESP. As shown in Fig. 1, White [9] illustrates how ESP's performance changes with particle's resistivity.

Unpleasant experiences are associated with both deficient resistivity and excessive resistivity. A resistivity below the lower limit leads to high re-entrainment because particles reaching the collecting electrode rapidly lose their charge, while high resistivity decreases the conductive ability of the particle making them difficult to charge and also slow to lose their charge when they reach the collecting electrode because of the low conductivity of the dust layer already deposited. This situation results in an effect called "back corona" [1,7].

1.1 Factors Affecting Resistivity of Cement

Cement and Cement Clinker Dust (CKD) generated during cement production are insulating materials, and this feature makes highly resistive. While data on the electrical resistivity of CKD from Nigeria cement manufacturing plants is not available, the electrical resistivities reported in studies conducted on CKD from foreign cement manufacturing plants are in the range of 10^7 – 10^{14} Ω·cm for temperatures ranging from 20℃ – 450℃ [7,10].

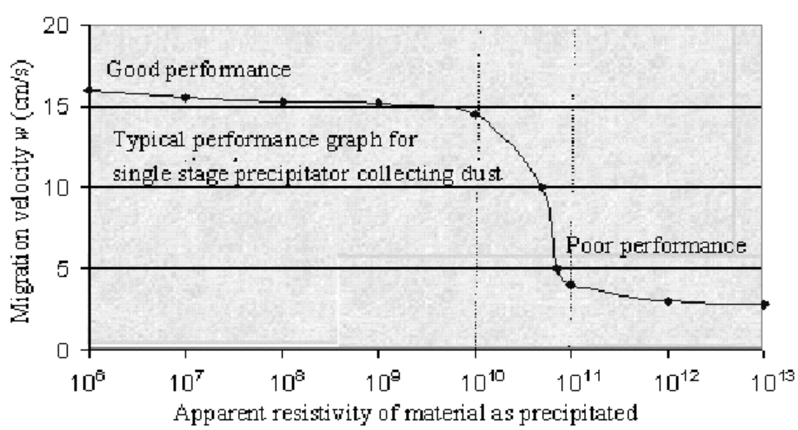
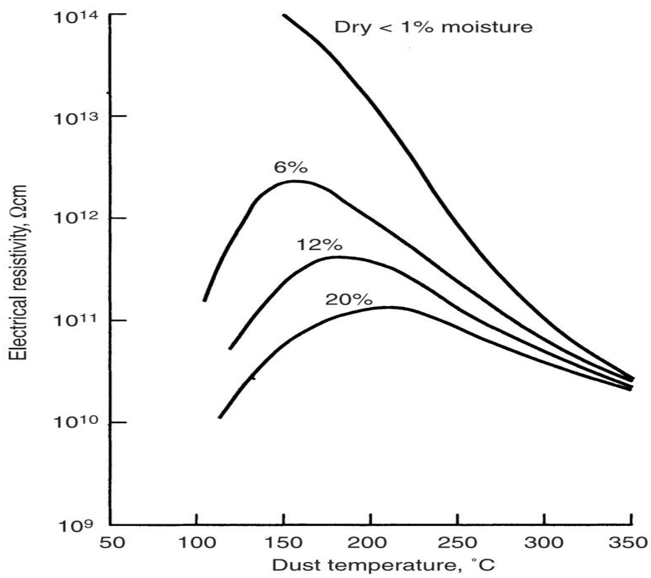


Fig. 1. Effects of particle resistivity on ESP performance [9]

The electrical resistivity of particulates is influenced by several factors including temperature, humidity, chemical composition and surface properties of the particles. The effect of variation in temperature and moisture content on the electrical resistivity has been reported by References [4,5] while References [5,7,11] have reported the influence of chemical composition of particulate on its resistivity.



1.2 Measurement Methods for Resistivity

Electrical resistivity is usually determined by basic calculation involving the resistance of the material and the geometry of the material when its resistance was measured. However, there are many methods for determination of the electrical resistance of materials, and by extension the resistivity. The two probes methods; the four probes methods; the Van der Pauw method, the Montgomery method, the spreading resistance technique, the pulse probe method, and the rotary magnetic field method have been reported [3,12,13]. While some of the methods share certain features in common, each differs in applicability and the type of material they are suitable for, References [3,14,15] have adequately compared these methods and their application.

1.3 Particulate Pollution around Nigerian Cement Plants

Electrostatic precipitator is a commonly employed particulate control device by local cement manufacturers in the Nigeria and a sizeable number of ESP' units are installed in all existing plants, yet there has been recurring dust-related pollution in communities where the cement manufacturing plants are located. Unfortunately, despite huge concerns over dust generated from cement production plants in Nigeria, few studies have assessed the performance of the ESPs employed in these plants and very little study had been done to investigate the particle-based variables that affect the effectiveness of the ESP. Specifically, no study has reported the electrical characteristics of particulates including CKD from local cement plants. This study bridges the existing gap.

Therefore, this study examines the electrical resistivity of dust generated from Nigerian cement plants, with the aim of tracing causes of performance problems associated with the ESP used for particulate control in these plants.The study will provide guidance for air pollution engineers, plant operators, and others directly concerned with the design of ESP and the troubleshooting of its performance problems.

2. MATERIALS AND METHODS

Cement dust were collected across all existing cement plants in Nigeria and were examined for their electrical resistivity. Dust collection was done from the hopper of the ESPs of these plants and each cement dust was labeled using the name of the plant from which it was sampled.

Multiplicity of test sample was adopted in order to capture the full nature and properties of the cement products which may vary due to the different sources of raw materials. Araromi [16] reported that the raw materials for cement production, most importantly limestone is usually quarried from local rocks which most often varies in concentration due to the presence of impurities and eventually impact the properties of the cement. The investigated samples are: Ewekoro, Ibese, Kalambaina, Obajana, Gboko, Ashaka, Okpella, Mfamosing, and Sagamu.

As earlier indicated, several experimental techniques are available for determination of electrical resistivity but the “Two probes method” was adopted in this study majorly because of the availability of instrumentation and its ability to handle highly resistive materials including cement. The fundamental principle of the two probe measurement technique is that when a constant voltage is applied across a specimen, the current that flows through the electrode attached to the specimen is inversely relative to the resistance of the specimen.

2.1 Materials

The materials used in the measurement are listed and explained below:

2.1.1 Electrometer

This is a digital sensitive multimeter which gives accurate measurement of very low current which can be used to determine resistance as high as giga-ohm and beyond. The electrometer (Keithley Model 6517B, Keithley Instruments Inc.) used in this work was sensitive to about 10^{-12} amp, permitting measurement of resistivities as high as 10^{15} ohm-cm.

2.1.2 Power source

A BK Precision high voltage power source was used to supply a steady direct current voltage as high as 1KV.

2.1.3 Oven

This is used for heating the sample in order to allow measurement of the resistivity at varying degree of temperature.

2.2 Methodology

The power source, electrometer and sample plate were connected as shown in Fig. 2. Using the DC power supply, a potential difference of 500V [17] was applied through the dust sample of 0.5 cm in thickness, placed in between two parallel rectangular stainless steel plates, closed up at both ends to form a cuboid-like structure with cross sectional area of 8 cm^2 and the electrometer measured the resulting current after waiting for 60 seconds, from which the resistance was calculated using ohm’s law (Eqn. 1). The resistivity were then determined using Eqn. 2.

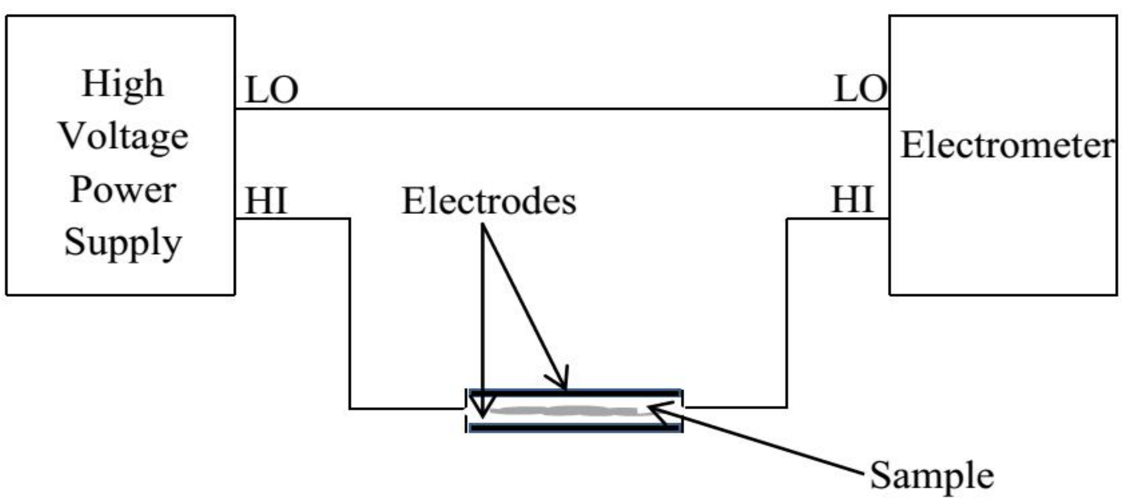


Fig. 2. Circuit configuration for resistivity measurement

$$R = \frac{V}{I} \quad (1)$$

$$\rho = \frac{R \times A}{L} \quad (2)$$

Where:

R = Resistance measured (Ω)
V = Voltage (volt)
I = Current (ampere)
A = Cross-sectional area of specimen (cm^2)
L = Thickness of specimen (cm)
ρ = Resistivity (Ω·cm)

To test for effect of temperature change on the resistivity of cement, the samples in between the electrodes were placed inside an oven and heated to desired temperature. Since an electrical feed-through could not be created on the oven wall, the samples were extracted from the oven before connection to the voltage source and the electrometer. In order to accommodate for heat loss on extraction of sample from the oven, samples were heated to a little degree above desired temperature. The temperature of the samples was varied from average ambient temperature of 26.5℃ to about 500℃ and resistivity measurement was taken at different temperature values. The temperature range was selected so as to model likely conditions of the cement dust at ambience and just after the kiln in real cement plants.

The samples were also tested at different size distributions in order to assess the effect of variation in particle size on electrical resistivity. To achieve this, the samples were sieved into seven average diameter portions (19 µm, 41.5 µm, 54 µm, 69 µm, 82.5 µm, 98 µm and 106 µm) using stack of sieves with the following mesh sizes: 38 µm, 45 µm, 63 µm, 75 µm, 90 µm, and 106 µm and the resistivity was measured at an average ambient temperature of 26.5℃ by following the procedure earlier explained.

3. RESULTS AND DISCUSSION

The electrical resistivity of cement samples determined at different temperature levels and as presented in Fig. 3 showed variation with the temperature. At 26.5℃, the samples exhibited close resistivity averaging at 10^8 ohm-cm, with the least being Ashaka dust at 1.89×10^8 Ω·cm and highest value at 6.36×10^8 Ω·cm for Okpella while other samples exhibited resistivity within the range. For all the samples analyzed, marginal increase in resistivity occur as a result of raising temperature from 26.5℃ to 100℃, and the values were still within 10^8 Ω·cm bracket with the highest resistivity recorded at 8.72×10^8 Ω·cm (possessed by Kalambaina) and the lowest value is 3.11×10^8 Ω·cm, still maintained by Ashaka. Upward rise in resistivity from 10^8 Ω·cm to as 10^{10} Ω·cm and 10^{11} Ω·cm were noticed at 200℃ and 300℃, respectively. The resistivity of the samples ranged from 2.11×10^8 Ω·cm – 4.99×10^8 Ω·cm at 200℃ and 1.85×10^{11} Ω·cm – 5.45×10^{11} Ω·cm at 300℃. However, Ewekoro still operated at 10^{10} ohm-cm bracket but with a significant figure (9.55×10^{10} Ω·cm) at 300℃. At temperatures of 400℃ and 500℃, decline in resistivity was observed with measurement located within 10^{10} Ω·cm and 10^9 Ω·cm brackets, respectively.

Resistivity within the range of 1.53×10^{10} Ω·cm and 5.61×10^{10} Ω·cm were obtained at 400℃, in this case Ewekoro exhibited the least resistivity while Okpella is on the highest side. At 500℃, the samples displayed resistivity of 1.52×10^9 Ω·cm – 7.52×10^9 Ω·cm, except Sagamu which operated as low as 8.50×10^8 Ω·cm. Between 26.5℃ and 300℃, the resistivity of the dust samples increased with temperature but for temperature above 300℃, the resistivity decreased as the temperature increases around 400℃ – 500℃. Of all the various resistivity value measured at different temperature, the samples were highly resistive at 300 ℃ and ESP's performance will be affected if the ambient temperature of the working fluid is around this margin. Efficient ESP operation for particulates around cement plants is achievable at temperatures below 200℃ and above 400℃, and therefore, ESP is suitable for particulate control at these temperatures.

Fig. 4 presents how each size class responded to electrical environment for all the samples. Gradual reduction in resistivity was noticed as the average size of the particle increases. For particles with average diameter of 19µm, resistivity measured was within the 10^9 Ω·cm average, precisely 1.05×10^9 Ω·cm – 2.25×10^9 Ω·cm. For the 41.5µm average sized particles, resistivity measured was between 10^8 – 10^9 Ω·cm, precisely 8.21×10^8 Ω·cm – 1.17×10^9 Ω·cm. The next four particle size distributions with average diameters at 54µm, 69µm, 82.5µm and 98µm have resistivity falling in the 10^8 Ω·cm bracket. For the 106µm particles, resistivity declined to as low as 9.8×10^7 Ω·cm.

The pattern observed for all the cement samples tested is the finer the particle, the higher the resistivity. The 106µm average diameter particles give resistivity in the lower limit of 10^8, precisely $9.80×10^7$ – $4.22×10^8$ ohm-cm. The resistivity displayed gradual increment in value as the particle diameter reduces reaching a value of $8.21×10^8$ – $1.17×10^9$ for the 19 micron particles. This is an indication that particles with large sizes respond better to electrical environment than smaller-sized particles and thus, the bigger the particle, the lower its resistivity at room temperature.

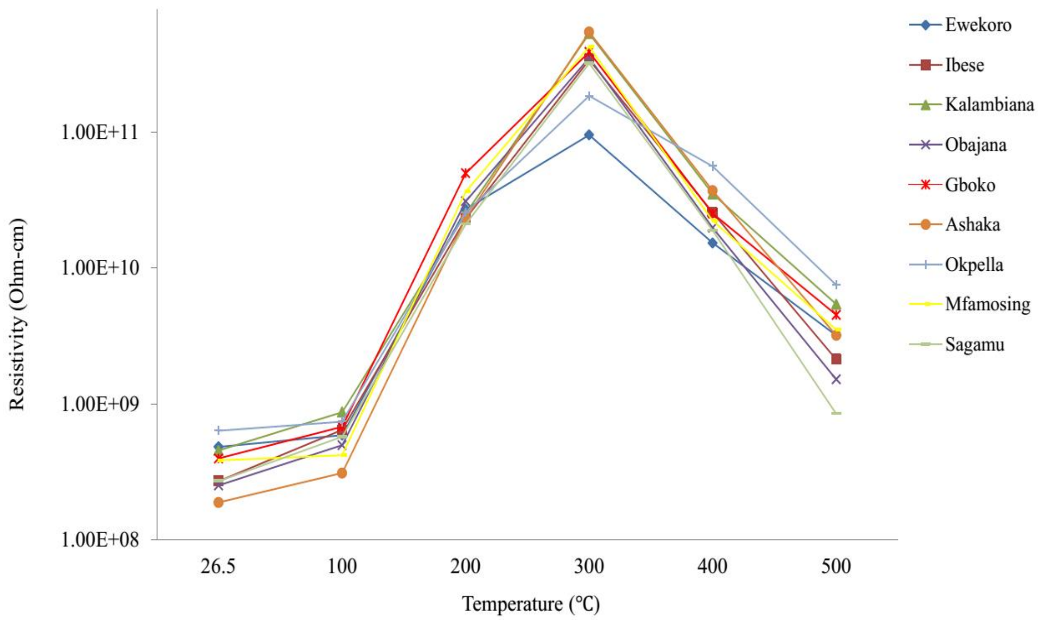


Fig. 3. Resistivity of the samples at varying tegrees of temperature

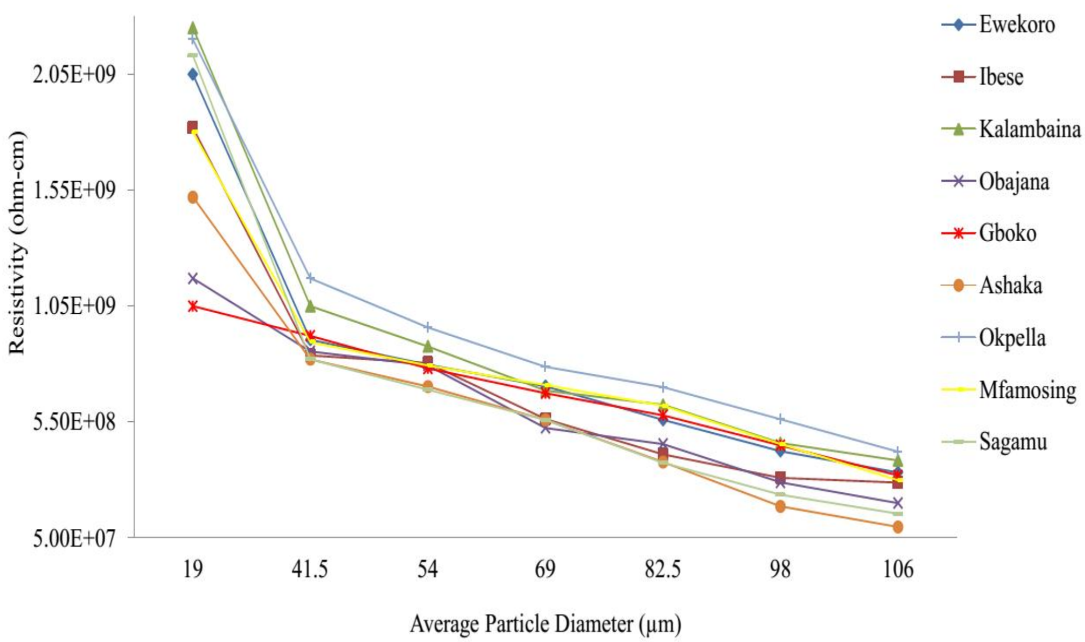


Fig. 4. Resistivity of distinct sizes of particles at ambient temperature (26.5℃)

4. CONCLUSION

The position of various literatures on normal resistivity of particles for optimum performance of an ESP are values between 10^8 ohm-cm and 10^{10} ohm-cm findings from the present study showed close agreement between the electrical resistivity of particulates from Nigerian cement plants and this requirement at certain temperature, which indicates that the cement dust will be captured very well by an ESP if the temperature of the carrier gas is regulated. Resistivity at temperatures 250℃ below and 400℃ above are adaptable for optimum ESP's performance. Coarser particle sizes are favourably disposed to optimum ESP's efficiency than finer particulates because the electrical resistivity of the particle displayed gradual increment in value as the particle diameter reduces.

It is general knowledge that when the resistivity of dust layer is high, at value of 2 x 10^{11} ohm-cm or more, back corona effect becomes prevalent in an ESP causing difficulties in charging the particles and considerably reducing the collection ability of the unit. A reverse but likewise unpleasant situation arises for resistivities below 10^8 ohm-cm, the particles are held on the plates so loosely that rapping and non-rapping re-entrainment becomes much more severe. Of all the various resistivity value measured at different temperature, only operation at 300 ℃ will resistivity poses a threat to ESP's performance.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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