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# Modelling Electrical Conductivity of Contaminated Nigerian riverbed Sands

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## Abstract

Investigation of electrical conductivity of contaminated earth is becoming increasingly relevant in geophysical sciences, where global environmental safety is a key issue. Riverbed sands were collected from the five south-western states of Nigeria, and electrical conductivity determined after samples have been contaminated with varying concentrations of petrol, cow dung, palm oil, manganese (IV) oxide, cement, cassava extract, wood ash, and washing soda. Impact of density was also studied for solid contaminant. Conductivity was largely proportional to contaminant concentration in all the samples in general. However with increase in concentrations of petrol and palm oil, decrease in electrical conductivity of samples was observed while increase in concentrations of other contaminants increased conductivity of samples. Conductivity was also largely influenced by the density of contaminated samples. At higher concentrations of contaminants, conductivity became constant especially when conductivity values of contaminants itself was achieved.

**Keywords:** Riverbed Sands, Electrical Conductivity, Contaminants, Density

## Introduction

In urban environments, riverbed sands receive considerable pollution from industry, traffic and refuse, and since contaminated soil particles can easily be inhaled or ingested, there is a potential transfer of toxic pollutants to humans (El Khalil *et al.*, 2008). Electrical conductivity plays a determinant role in two complementary aspects of the exploration of the ground: surface measurements and well-logging measurements (Keller, 1988; Tabbagh *et al.*, 2002). This property exhibits the widest range of variation among all the properties used in exploration geophysics. Furthermore, the concept of electrical conductivity had found a very good use in Agriculture.

The conductivity meters measure the number of ions that are mobile within a liquid and the measurement of electrical conductivity is considered the most accurate way of determining the salinity of the soil. Plants absorb nutrients in form of ions e.g. nitrogen ions, phosphorous ions and potassium ions (NPK) and measuring a soil solution is a good indication of the total amount of nutrients available to the plants (although not the specific nutrients).

In petroleum engineering, it is frequently assumed that the electrical conductivity has contributions from both the liquid and solid phases (Patnode and Wylie, 1950; Cremers and Laudelout, 1965; Rhoades *et al.*, 1976). Electrical conductivity has also been used to estimate diffusion in porous media (Snyder, 2001; Garrouch *et al.*, 2001, Klein and Santamarina, 2003). Electrical conductivity depends on the concentration of the ions, temperature of the solution and the nature of the ions (Waxman and Smits, 1968; Bussian, 1983). Given the presence of industrial and agricultural activities around major rivers in south-western Nigeria, contamination has been a major issue. However, information about the electrical properties of contaminated Nigerian sands is very scarce despite their potential usage as ceramic tiles and bricks in building constructions. This work was therefore aimed at assessing the electrical properties of Nigerian riverbed sands which are highly impacted by human activities with increase in packing densities and local contaminants concentrations. The results of this study should therefore be sufficiently representative of the present situation to constitute guidance for future research which will help to develop management and remediation strategies.

## Materials and Method

Riverbed sands were collected from the five south-western states of Nigeria as presented in Table-1 and Fig. 1. Samples were thoroughly washed to remove any hidden contaminant, oven-dried and sieved to ensure uniform grain sizes. Electrical conductivity was measured by a conductivity meter at a constant room temperature (25$^{\circ}$C). The contaminants used were petrol, cow dung, palm oil, $MnO_2$, cement, cassava extract, wood ash, and washing soda. Most of the pollutants are agricultural and industrial wastes, with block making industries using cements, saw mills converting saw dust to wood ash, local palm oil industries, and cassava extract produced by cassava flour producers.

### Petrol

Petrol is a fuel derived from petroleum crude oil and used in spark-ignited internal combustion engines. Conventional gasoline is mostly a blended mixture of more than 200 different hydrocarbon liquids ranging from those containing 4 carbon atoms to those containing 11 or 12 carbon atoms (Speight, 2008).

### Cow dung

Cow dung is the waste of bovine animal species especially domestic cattle. Cow dung is the undigested residue of herbivorous matter, having passed through the animal's gut, and passed out as resultant faecal matter which is rich in minerals. Colour ranges from greenish to blackish, often darkening in colour soon after exposure to air. In many parts of the developing world, the banks of the river and dry river beds are contaminated with cow dung as cows are led to wander about and looking for rivers to drink water. Chemical composition of cow dung revealed that it contains organic matter, Nitrogen (N) and Manganese (Mn) (Kumar and Vishal, 2007).

### Palm oil

Palm oil is obtained from the mesocarp of the *Elaeis guineensis* fruit, simply by cooking, mashing and pressing. Palm oil extraction is predominantly done by rural women around rivers especially because of the volume of water required during the production of oil. Seeds are separated and after cracking and removing the shell, the kernel processed to yield palm kernel oil and palm kernel cake. Refined, Bleached and Deodorized (RBD) palm oil is obtained from refining crude palm oil. Palm oil is a light yellow liquid and semi-solid at room temperature, melting to a clear yellow liquid on slight heating. It naturally contains carotenes (pro-vitamin A) which give red colour to the oil. Palm oil processing is predominantly the activity of most rural dwellers, and the disposed extract mixes with soils and ends up affecting water quality of streams and rivers especially during the rainy season.

## Manganese (IV) Oxide

Manganese (IV) oxide is a blackish solid used in Lechlanche dry cell where it is contained in a muslin bag round the carbon pole to function as a depolarizer. $MnO_2$ is a poor conductor and therefore has to be mixed with powdered carbon, which is a good conductor. When a primary cell works continuously, it depolarizes owing to the hydrogen librated at the carbon pole. According to Oniawa and Fakayode, 2010, Lead levels measured in the vicinity of a battery factory in Nigeria were found to be elevated around the factory with average levels of about 2000 mg $kg^{-1}$ close to the fence but decreased gradually to about 50 mg $kg^{-1}$ some 750 m away.

## Cement

Portland cements are commonly characterized by their physical and chemical properties for quality control purposes. They are common building materials used for constructions of bridges and buildings and for plastering and concreting of blocks. The ability to easily mix with soils makes cement, which is mostly used for construction materials, end up in streams and rivers, thus affecting water quality which many rural populace drink in developing countries. The constituent components include Tricalcium Silicate ($3CaO.SiO_2$), Dicalcium Silicate ($2CaO.SiO_2$), Tricalcium Aluminate ($3CaO.Al_2O_3$), Tricalcium Aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$) and Gypsum ($CaSO_4.H_2O$). According to a research conducted by Olaleye and Oluyemi, 2009 in the vicinity of Ewekoro cement factory in Nigeria, high levels of total dissolved particulates and atmospheric deposition rates were recorded, with planktonic flora and fauna of the river systems draining the area very poor.

## Cassava extract

Cassava is annually cultivated as annual crops in tropical and subtropical regions of the world. It is the third largest source of carbohydrates for human food in the world, with Africa being the largest centre of production (Claude and Denis, 1990). Cassava contains cyanide (Arguedes and Cook, 1982), either in expressed juice or wash water spray (Cook and Maduagwa, 1987), and the effluent from cassava is usually disposed as waste water. According to a research conducted by Ehiagbonare *et al.*, 2009 on the impact of cassava effluent on the surrounding waters, it was observed that the colour, taste, odour and quality of the waters changed after cassava effluent have been discharged into it from the neighbouring cassava processing base. Environmental problems from cyanide may occur; for example growing stages of plants including vegetables and sensitive stages of fish and other aquatic animals may be negatively affected (Bengtsson and Trient, 1994).

## Wood Ash

Wood ash is the inorganic and organic residue remaining after the combustion of wood or unbleached wood fibre. The physical and chemical properties of wood ash vary significantly depending on many factors. Hardwoods usually produced more ash than softwoods and the bark and leaves generally produce more ash than the inner woody parts of the tree. On the average, the burning wood results in about 6-10 per cent ash. Bush burning is a major trend in most African countries, especially as a means of clearing overgrown bushes, and also by hunters during dry seasons. It mixes easily with sands and is a major contaminant of water in rivers which are primary sources of drinking water in rural areas. It has been established that wood ash is an unusual cause of irritations and chemical burns when in contact with human skins (Kilic and Kilic, 2002).

**Washing soda**

Sodium carbonate (also known as washing soda, $Na_2CO_3$) is a sodium salt of carbonic acid. It most commonly occurs as a crystalline heptahydrate, which readily effloresces to form a monohydrate white powder and is domestically well known for its everyday use as a water softener. Production of washing soda is very common in most Nigerian households, and soda residues are usually disposed in careless manners, making them contaminate the soils and shallow/surface waters especially during rainy season. Redness and burning of eyes, redness and swelling of skin, nose and/or throat irritation, nausea and/or vomiting are some of the known health hazards (USOSHA, 1985).


**Fig 1:** Map showing sample locations.

## Sample Preparation

0.2 kg of each sample was moistened with 30 ml of distilled water. Several readings of electrical conductivity were taken at different points in the cylinder in order to obtain the average values. $0.000005m^3$ of each contaminant was then added and mixed thoroughly, after which conductivity was measured. The concentration of the contaminant was increased by the same volume at each experimental set-up until dose of the concentration reached a level of $0.00003m^3$. Measurements were made following the procedure explained above with 0.3, 0.4, 0.5, and 0.6 kg of the samples. For all the contaminants where the concentration of solid contaminants was by masses (kg) *i.e.* Cow dung, Manganese (IV) oxide, Cement, Wood ash and Washing soda, a sensitive scale was used to achieve the accuracy.

In the second round of experiments, the concentration of cassava liquid waste was dosed with 0.3 kg of each sample step-by-step by increasing the concentration and conductivity was measured at each experimental step while sample dose was increased till the measured conductivity became constant.

In the third part of the work, 0.3 kg of the samples with 30 ml of the water was thoroughly mixed in a beaker with 0.00001 kg of $MnO_2$. The mixture was then transferred into a container and compressed to different densities and conductivity measured at each density. The process was repeated for the remaining two solid contaminants *i.e.* Cement and Wood ash.

**Table-1:** Sample location parameters and natural conductivity values.

| Sample | River Name | State | Elevation (m) | Porosity | Latitude | Longitude | Electrical Conductivity (µs/cm) |
|---|---|---|---|---|---|---|---|
| A | Lekki Beach | Lagos | 5 | 0.432 | 6° 25´ N | 3° 31´ E | 58 |
| B | Owena | Ondo | 208 | 0.343 | 7° 10´ N | 4° 43´ E | 254 |
| C | Water Works | Osun | 263 | 0.396 | 7° 38´ N | 4° 12´ E | 65 |
| D | Odoona | Oyo | 160 | 0.401 | 7° 23´ N | 3° 51´ E | 386 |
| E | Isolu | Ogun | 64 | 0.394 | 6° 48´ N | 3° 13´ E | 146 |

## Results and Discussion

Increase in the weight of samples while maintaining same amount of contaminants had little impact on sample (A) from Lekki Beach which had the smallest variations in conductivity values with regards to sample weight increment, as markedly opposed to other samples with pronounced variations in conductivities as weights of samples increase. Incidentally, Lekki Beach which is the most porous sample as shown in Table-1 also had the highest conductivity after contamination irrespective of sample weights. Samples with widest variations were those obtained from Odoona and Isolu.

### Slope Analysis

Analysis of slopes for the plots of variations of conductivity with increment of contaminant concentrations was carried out as shown in Table-2 for Petrol, Cow dung, Palm oil, Manganese (IV) Oxide and Cement, while Table-3 shows the slope analysis for Cassava liquid waste, Wood ash and Washing soda. The slope analysis clearly revealed that values of gradients reduced with masses of samples, as equal amount of contaminants was being added irrespective of the samples.

### Conductivity against Concentration

Conductivity variations with contaminants for the various samples were carried out but only the plots for Petrol (representing liquid contaminants) and Manganese (IV) oxide (representing solid contaminants) were shown. Conductivity decreased with increase in concentration of petrol in all the samples as shown in Fig. 2 to 6. Petrol as a covalent hydrocarbon is a poor conductor of electrical current. The electrical conductivity on the other hand increased with increase in the concentration of cow dung as shown in Table-2. The cow dung used in the study consisted of the following chemical composition: 1.6% N, 0.70% P, 0.53% K, 0.91% Mg, 2.71% Ca, 0.50% Na, 56.8% organic matter and C:N of 7.9 (Onwudike, 2010), which has resulted in the observed conductivity trend.

Conductivity decreased with increase in the concentration of palm oil as observed in Table-2 with negative gradient as was the case with petrol. Palm oil is also made up of covalent bond, and thus behaved in a similar way as petrol. Conductivity increased with increase in density of $MnO_2$ as shown in Fig. 7 to 11. Although $MnO_2$ is a poor conductor, chemical composition analysis however revealed that the conductivity behaviour is due to $MnO_2$ being usually mixed with powdered carbon which is a good conductor. From the studies on cement dosages, the results revealed that the conductivity increased with increase in concentration of cement as shown in Table-2 with positive gradient. The increase in conductivity was probably contributed by calcium which is a very reactive element in the chemical composition of cement. In the activity series, calcium reacts with water to form hydroxide (Ca $(OH)_2$). Calcium comes third in the activity series, Potassium (K) and Sodium (Na) takes the first and second positions respectively.

**Table-2:** Slopes of Conductivity Vs Concentration of 5 contaminants for different samples.

| | **Petrol ($m^3$)** | | | | |
|---|---|---|---|---|---|
| Sample | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | -3E +06 | -3E +06 | -2E +06 | -2E +06 | -2E +06 |
| B | -2E +06 | -1E +06 | -972571 | -694857 | -720000 |
| C | -2E +06 | -2E +06 | -1E +06 | -8937 | -769143 |
| D | -2E +06 | -2E +06 | -2E +06 | -1E +06 | -1E +06 |
| E | -2E +06 | -2E +06 | -2E +06 | -1E +06 | -982653 |
| | **Cow dung (kg)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 2611.7 | 2470.3 | 2161 | 2124.3 | 2053.1 |
| B | 1733.7 | 1455.4 | 1369.1 | 1249.4 | 932 |
| C | 1936 | 1604.6 | 1428.9 | 1212.9 | 1043.1 |
| D | 1472.3 | 1282.6 | 1054.9 | 921.71 | 756.57 |
| E | 2035.4 | 1706.3 | 1326 | 1344.3 | 931.43 |
| | **Palm oil ($m^3$)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | -2E +06 | -2E +06 | -2E +06 | -2E +06 | -2E +06 |
| B | -2E +06 | -1E +06 | -883429 | -690286 | -472571 |
| C | -2E +06 | -1E +06 | -882286 | -800000 | -739429 |
| D | 1E +06 | -894857 | -684571 | -660571 | -381714 |
| E | -2E +06 | -2E +06 | -2E +06 | -1E +06 | -899429 |
| | **$MnO_2$ (kg)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 277629 | 237586 | 181414 | 164214 | 146829 |
| B | 59166 | 48583 | 33211 | 25040 | 14149 |
| C | 62674 | 49897 | 41817 | 32537 | 22069 |
| D | 45577 | 35360 | 29063 | 22903 | 10651 |
| E | 69383 | 50446 | 41257 | 24023 | 29349 |
| | **Cement (kg)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 67977 | 64160 | 57851 | 43303 | 36537 |
| B | 43703 | 40891 | 31600 | 28034 | 20469 |
| C | 50571 | 38777 | 38777 | 28960 | 24823 |
| D | 40023 | 36480 | 36046 | 23977 | 20366 |
| E | 50331 | 40823 | 36240 | 34617 | 25143 |

For cassava liquid waste, conductivity increased sharply, with increase in its concentration as observed in the slopes analysis as shown in Table-3. It is characterized by 1,300 ppm of $CN^-$ which had strong influence on the electrical conductivity behaviour of the samples dosed with cassava liquid. Same trend was observed with wood ash (Table-3) where conductivity also increased with increase in concentration, though not as sharply as cassava extract. Calcium is the most abundant element in wood ash, which also is a good source of potassium, phosphorus, magnesium and aluminium all of which are conductive ions. From Table-3, conductivity was observed to increase with concentration of washing soda. Electrical conductivity increase was also very sharp in soda, and the variation in conductivity values across the samples was very minimal. Sodium carbonate ($Na_2CO_3$), sodium bicarbonate ($NaHCO_3$), sodium hydroxide (NaOH) and sodium oxide ($Na_2O$) are all sodium salts that might have contributed for the conductivity behaviour.

Furthermore, range of conductivity values was analysed for the investigated contaminants with sample weight 0.2 kg as shown in Table-4. Samples dosed with Petrol and Palm oil contaminants fall within the lowest conductivity range, while Washing soda and Cassava extract fall within the highest conductivity range. However, at some instances, Washing soda and Cassava extract also fall within the middle range of conductivity.

**Table-3:** Slopes of conductivity Vs Concentration of 3 contaminants for different samples.

| | **Cassava liquid waste ($m^3$)** | | | | |
|---|---|---|---|---|---|
| Sample | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 3E +07 | 3E +07 | 3E +07 | 3E +07 | 2E +07 |
| B | 3E +07 | 2E +07 | 2E +07 | 2E +07 | 2E +07 |
| C | 3E +07 | 2E +07 | 2E +07 | 2E +07 | 2E +07 |
| D | 2E +07 | 2E +07 | 2E +07 | 2E +07 | 1E +07 |
| E | 3E +07 | 2E +07 | 2E +07 | 2E +07 | 2E +07 |
| | **Wood ash (kg)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 63840 | 63223 | 47840 | 43771 | 40514 |
| B | 48297 | 34857 | 26960 | 21874 | 18457 |
| C | 45131 | 35017 | 28594 | 24914 | 22034 |
| D | 43931 | 28971 | 22309 | 24343 | 16034 |
| E | 48160 | 34960 | 33989 | 31349 | 26983 |
| | **Washing soda ($m^3$)** | | | | |
| | 0.2 kg | 0.3 kg | 0.4 kg | 0.5 kg | 0.6 kg |
| A | 3E +07 | 3E +07 | 2E +07 | 2E +07 | 2E +07 |
| B | 2E +07 | 2E +07 | 2E +07 | 1E +07 | 1E +07 |
| C | 2E +07 | 2E +07 | 2E +07 | 1E +07 | 1E +07 |
| D | 2E +07 | 2E +07 | 1E +07 | 1E +07 | 1E +07 |
| E | 2E +07 | 2E +07 | 2E +07 | 2E +07 | 1E +07 |

Comparing the electrical conductivity values at natural locations in Table 1 with Table-4 revealed that samples B, D and E were more contaminated than A and C. This was expected from the point of view of human activities around B, D and E as opposed to A and C that were not directly within residential areas. For instance, Sample E was taken from Isolu river which is very close to the University of Agriculture, Abeokuta off campus residential area characterized with a lot of human activities including new building constructions.

## Conductivity at Higher Concentrations

Conductivity of sample A was observed to be highest as compared to other samples at lower concentrations. It was also already observed for all the samples investigated that conductivity varied linearly with the increase in concentration. However, behaviour of conductivity at very high concentrations was investigated with cassava liquid waste as shown in Fig. 12. Cassava liquid waste was selected for the test because its slope analysis in Table-3 revealed very steep slopes and close values of gradients. At very high concentrations of cassava liquid waste, conductivity was largely constant for the samples and finally converged. The observed convergence of conductivity irrespective of the samples was most probably due to ionic interference which is restricting the mobility of the ions.

**Table-4:** Contaminant Type and Range of Conductivity from Experiment.

| Electrical Conductivity Range (µs/cm) | Possible Contaminant Type |
|---|---|
| 55 – 150 | Petrol, Palm Oil |
| 150 – 500 | Cement, Washing Soda, Cassava Extract, $MnO_2$, Wood Ash, Cow Dung |
| 500 – 1000 | Washing Soda, Cassava Extract |

**Conductivity against Density**

The graphs of conductivity against density of the samples dosed with Manganese (IV) Oxide, Cement and Wood ash were shown in Fig. 13 to 15. Sample A consistently remained the highest conductive, while the least conductive was sample D. It was also observed that for all the samples, the conductivity increased linearly with increase in the density of the sample. It is expected that due to increase in density, the particles of the porous media are brought more closely together along with the particles of the contaminant, thus making the ions to be locked in the pores.

## Conclusion

The presence of contaminants greatly influences the conductivity of porous media. A contaminant with lower or zero Total Dissolved Solids value *e.g.* palm oil reduced conductivity while that with higher Total Dissolved Solids value *e.g.* cement and cassava liquid waste increased conductivity of dosed samples. This is similar to what obtains in doped extrinsic semiconductors where the degree of doping makes a large difference in the conductivity with more doping implying higher conductivity.

In moderate concentration ranges, conductivity was proportional to concentration and largely dependent on the density (of the samples), the denser the sample the more closely packed the particle and the more conductive it is. At higher concentrations of contaminant like cassava liquid waste, the conductivity levelled off despite the increase in the concentration, and converged irrespective of the samples.

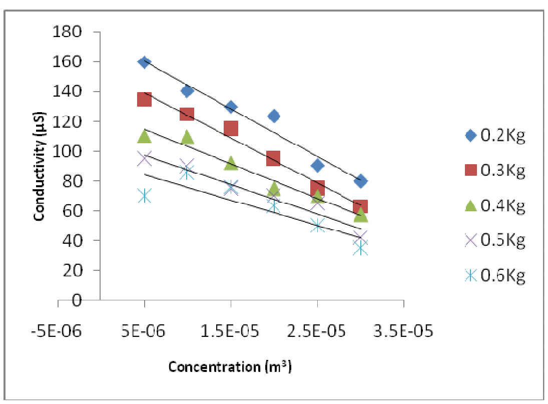


**Fig. 2:** Conductivity against concentrations of Petrol for various masses of Sample A

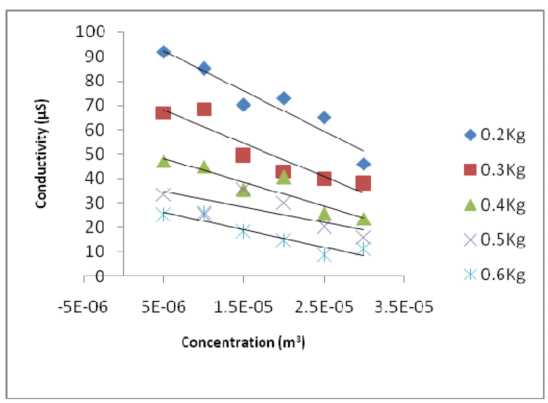


**Fig. 3:** Conductivity against concentrations of Petrol for various masses of Sample B

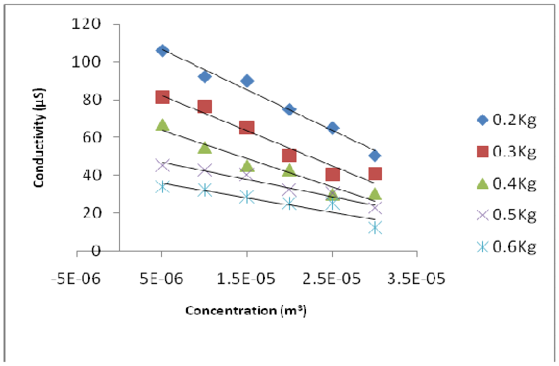


**Fig. 4:** Conductivity against concentrations of Petrol for various masses of Sample C.

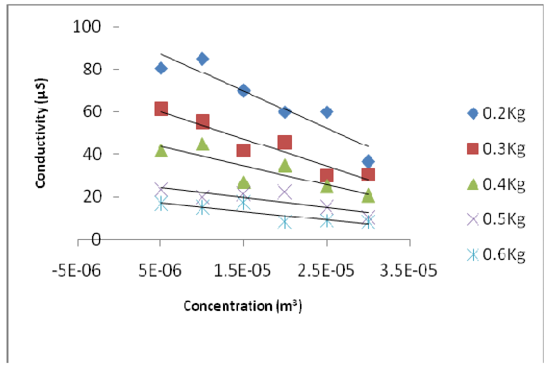


**Fig. 5:** Conductivity against concentrations of Petrol for various masses of Sample D.

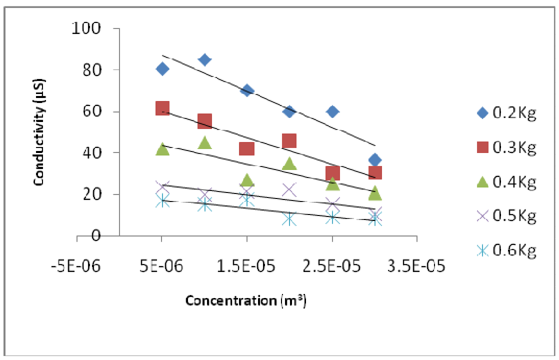


**Fig. 6:** Conductivity against concentrations of Petrol for various masses of Sample E.

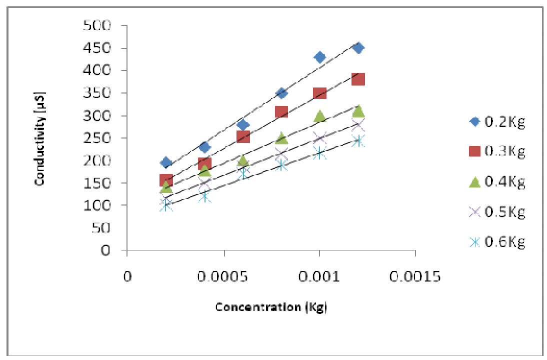


**Fig. 7:** Conductivity against concentrations of Mn $O_2$ for various masses of Sample A.

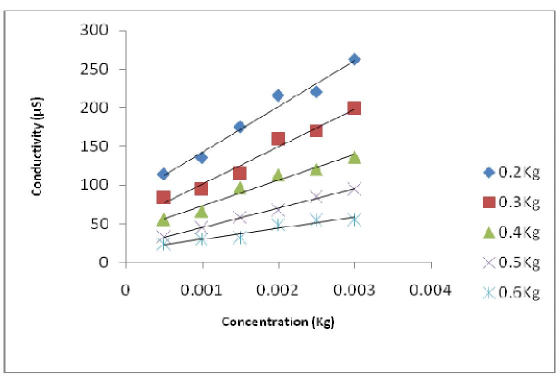


**Fig. 8:** Conductivity against concentrations of Mn $O_2$ for various masses of Sample B.

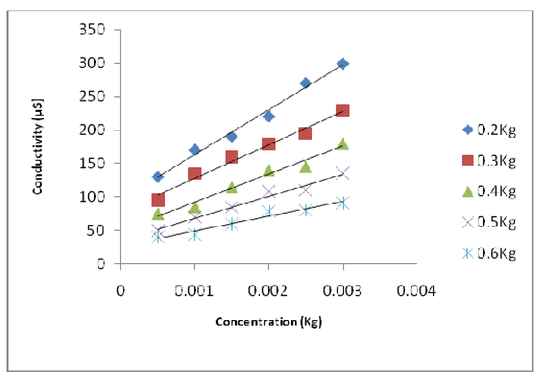


**Fig. 9:** Conductivity against concentrations of Mn $O_2$ for various masses of Sample C.

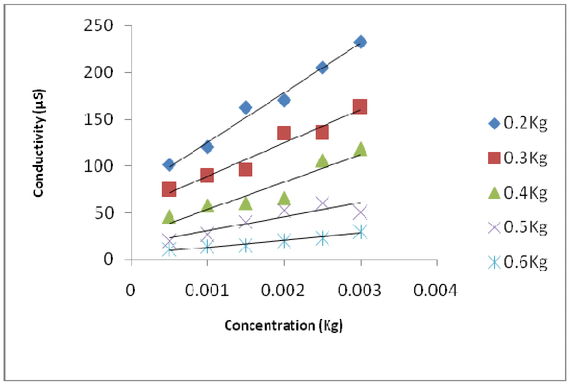


**Fig. 10:** Conductivity against concentrations of Mn $O_2$ for various masses of Sample D

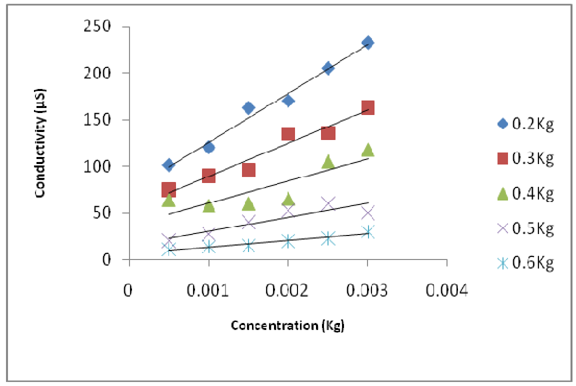


**Fig. 11:** Conductivity against concentrations of $MnO_2$ for various masses of Sample E.

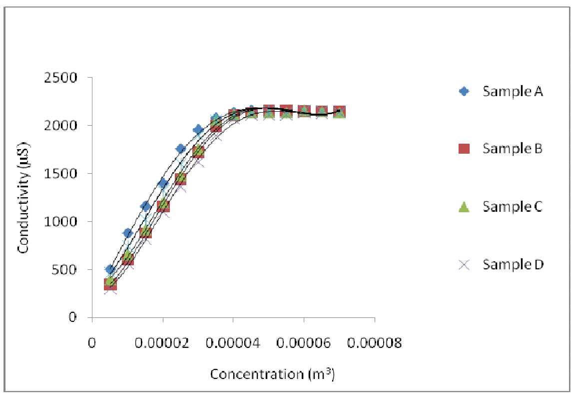


**Fig. 12:** Conductivities of the samples at higher concentrations of cassava liquid waste.

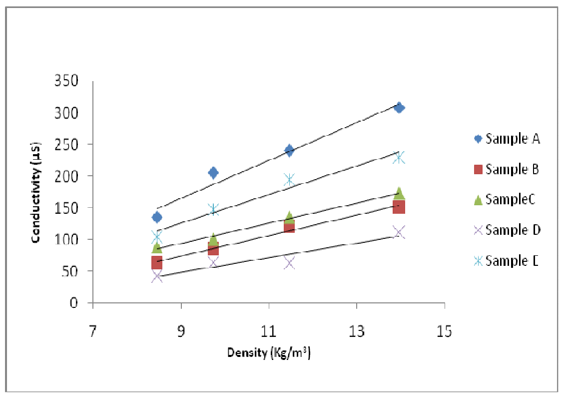


**Fig. 13:** Conductivity against density of samples contaminated with $MnO_2$.

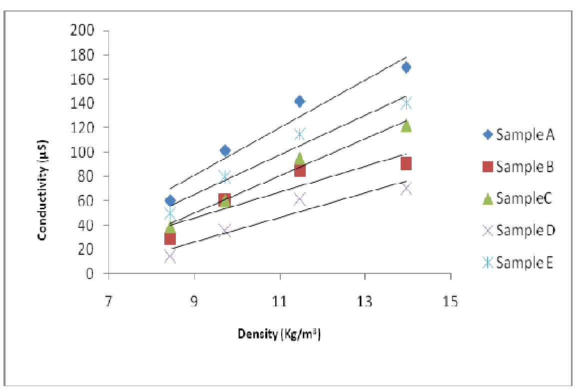


**Fig. 14:** Conductivity against density of samples contaminated with Cement.

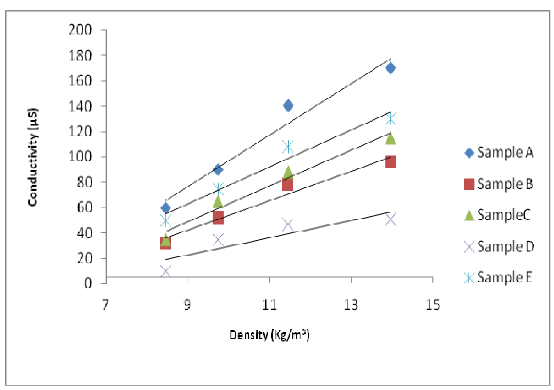


**Fig. 15:** Conductivity against density of samples contaminated with Wood Ash.

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