Comparison of Electrical Resistivity of Soots Formed by Combustion of Kerosene, Diesel, Aviation Fuel and their Mixtures

Sunday E. Etuk¹, Joseph B. Emah², Ubong W. Robert², Okechukwu E. Agbasi^{*3}, Inyang A. Akpabio²

¹Department of Physics, University of Uyo, Uyo, Nigeria

²Department of Physics, Akwa Ibom State University, Ikot Akpaden, Mkpato Enin, Nigeria

³Department of Physics, Michael Okpara University of Agriculture, Umudike, Nigeria

Keywords

Aviation fuel,
Diesel,
Electrical resistivity,
Kerosene,
Soot

Abstract

This research paper presents analysis of electrical resistivity values of soots formed by combustion of kerosene, diesel fuel, aviation fuel (Jet A.1), that of kerosene -diesel mixtures at different proportions and that of aviation fuel (Jet A.1)-diesel mixtures at various percentages. The results of the analysis reveal that soots formed by combusting kerosene, diesel, aviation fuel (Jet A.1) and their respective mixtures have electrical resistivity values ranging from $3.516 \times 10^{-1} \Omega m$ to $1.836 \times 10^{-1} \Omega m$. Soot from diesel fuel has the lowest value whereas soot from kerosene has the highest value of electrical resistivity. The obtained values are within the range of electrical resistivity values for materials classified as semiconductors. Electrical resistivity varies non-linearly with percentage composition of mixture constituents for soot formed by combusting kerosene-diesel mixture or aviation fuel (Jet A.1)-diesel mixture. Soot produced by combustion of pure diesel fuel has less resistivity value, indicating higher conductivity than soot obtained from the burning of aviation fuel whereas soot got from the combustion of kerosene exhibits higher electrical resistivity value than the former. This work has provided a database on the electrical resistivity values of soot (kerosene, diesel fuel, aviation fuel (Jet A.1)) formed as a result of combustion of some fuels and their mixtures for probable utilization by electrical, electronics and petroleum industries. Such database is being reported for the first time, hence making this research work a novel.

1. Introduction

When complex mixtures of several different molecular components such as kerosene (for cooking), kerosene (for aircraft engine), diesel and gasoline (for heavy duty and car engines) are burnt, soot is formed. Blanquart and Pitsch (2008) [1] reported on modeling soot formation in kerosene and fuel surrogate combustion. Colket et al. (2007) [2] confirmed that the fuels referred to above are mixtures of several components, formulated as surrogate. Combustion of gasoline, kerosene and diesel gives rise to soot formation. The soot so formed can be spherical and fractal aggregates [3 – 6]. Blanquart et al. (2008) [7] and Appel et al. (2000) [8] in their work noted that soot modelling is based on the polycyclic aromatic hydrocarbons formation as well as combustion depending on comprehensive chemical mechanism of the individual fuel components. While Schuetz and Frenklach (2002) [9] attributed the arrival of initial soot particles to take place as a result of collision of polycyclic aromatic hydrocarbons molecules, the collision of the particles with other particles lead to further growth, hence increase in mass due to chemical reactions [10]. Therefore, formation of massive growth of polycyclic aromatic hydrocarbons molecules as well as soot particles has certain constituents including benzene, acetylene, propargyl radical, toluene playing important role.

The supporting information of the work of Lam et al. (2012) [11] showed particulate contamination of kerosene in Uganda and USA to be 6.80 mg / L and 1.11 mg / L respectively. Their reports also revealed percent of household using kerosene for lighting by 37 countries and regions with Kenya in Eastern Africa recording 87% being the highest percentage of household using kerosene as primary lighting [12], followed by Uganda with 80 % [13], Nigeria in Western Africa with 75 % [14], Jordan in middle east having the lowest being 1 % [15] among others.

It is expected that the electrical resistivity values of soot got from combustion of contaminated fluid would vary with that of the soot

from the burning of a pure discrete combustible fluid at the same experimental temperature. Kerosene in its pure state is used for cooking as well as lighting or illumination to expel darkness. Diesel in its pure state is used as fuel for operation of locomotive engines and generators. Aviation fuel (Jet A.1) in its pure state has application in the operation of aircraft engine. It is obvious that in some cases, suppliers of these products adulterate one product with another either for the purpose of making profit or top up one product with another to make up for quantity required. Such adulteration is bound to alter the properties of the original pure fluid. This work is purposed to investigate the electrical resistivity of soots formed as a result of combustion of kerosene, diesel, aviation fuel (Jet A.1), mixture of kerosene and diesel, and mixture of aviation fuel and diesel in order to establish their usefulness in electrical and electronic industries, archeological studies and also ascertain the application of the resistivity values as quality control parameters in petroleum industry.

2. Theory

Electrical resistivity is both intrinsic and bulk property of a material. It expresses the electrical resistance that is offered to the flow of a direct current by a material of homogeneous unit cube that has uniform density between opposite faces of the cube. Determination of electrical resistivity is often carried out by computation using electrical resistance of the material, its known used length, and uniform cross-sectional area in accordance with the equation [16 – 17].

$$\rho = \frac{R_a}{L} \quad 1$$

where ρ is the electrical resistivity, R is the measured resistance, a is the cross-sectional area, and L is the length of the studied material. Electrical resistivity is measured in Ohm-metre. Pure metals are reported to have electrical resistivity values ranging from $1.5 \times 10^{-8} \Omega m$ to $1.35 \times 10^{-6} \Omega m$ at room temperature. While silver has the least

*Corresponding Author: agbasi.okechukwu@gmail.com
(Okechukwu E. Agbasi: 0000-0001-5649-0107)

Received 26 Dec 2020 Revised 18 Feb 2021 Accepted 18 Feb 2021
Brilliant Engineering 3 (2021) 6-10
2687-5195 © 2019 ACA Publishing. All rights reserved.

<https://doi.org/10.36937/ben.2021.003.002>

resistivity value, manganese is seen to have the highest resistivity value. The electrical resistivity values of some metallic alloys are known to fall within the above given range, whereas for insulators at room temperature, the approximate range of their electrical resistivity values is given to be from 10^8 to 10^{16} Ωm . More so, the electrical resistivity range for semiconductor materials at room temperature is approximately between 10^{-4} to 10^5 Ωm . However, temperature coefficient can be either positive or negative. Practically, metals and certain semiconductor materials show change in resistivity as they are placed in a magnetic field [17].

Temperature dependency of resistivity within a certain range of temperature for a large number of metals is governed by the equation expressed by Morris (1996) [18], Scherz and Monk (2016) [19] as

$$\rho_T = \rho_0 [1 + \alpha(T - T_0)] \quad 2$$

where ρ_0 denotes the resistivity at a reference temperature, T_0 commonly taken as 0°C or 20°C , ρ_T is the electrical resistivity at temperature, T lower or higher than T_0 , and α is the temperature coefficient of resistance given in units of $1/^\circ\text{C}$ or $^\circ\text{C}^{-1}$.

Most metals, have their resistivity increased with increase in temperature due to the fact that lattice atom vibrations resulting from thermal energy, increased temperature cause the drift velocity of conducting electrons to be impeded. A proper conductor has resistivity value of about 10^{-8} Ωm . Also, a pure insulator has resistivity value to be around 10^{14} Ωm , whereas that of an ideal semiconductor ranges from 10^{-5} Ωm to 10^3 Ωm depending on temperature [19 – 20].

The infinitesimal explanation for the variation in electrical resistivity of metals, conductors, insulators and semiconductors is owing to the quantum characteristic of electrons. Viewing from Classical Physics perspective, the energy values of an electron in metals form a continuum, causing electron energy at infinite distance from the nucleus to be zero. The quantum elucidation of electrons in metals indicates quantization of energy values of electrons. At room temperature, the electrical resistivity of a semiconductor material is mid-way between that of a good electrical conductor and that of a good electrical insulator.

Electrical resistivity principle has several applications ranging from electrical and electronics, geotechnical operations such as dam-site investigation, study of seepage zones [22 – 24], determination of sub-surface contamination in the vicinity of refuse dump [24 – 25], routine hydro-geological investigations in the area of complex geology [26]. Noel and walker (1970) [27] observed that, in addition to the above, electrical resistivity is used in archeological studies.

Theraja and Theraja (2003) [28] and Theraja (2008) [29] expressed electrical resistivity in terms of electron charge e , number of free electrons per unit volume of the conductor, that is the electron density n and electron mobility U_e , thus

$$R = \rho \frac{L}{a} \quad 3$$

$$\rho = \frac{1}{neU_e} \quad 4$$

$$R = \frac{L}{a} \frac{1}{neU_e} \quad 5$$

Young and Freedman (2008) [30] defined electrical resistivity of a material mathematically, thus

$$\rho = \frac{E}{j} \quad 6$$

E being magnitudes of electrical field and j the current density.

Whereas [15] observed that every material used as a conductor of electricity exhibits some resistance to the flow of electric current at normal temperature, Nung (1972) [31] averred that a perfect conductor of electricity would have zero resistivity and a perfect insulator an infinite resistivity

3. Methods

3.1. Materials and their description

Materials used for this investigative study included kerosene, diesel, aviation fuel (Jet A.1). The kerosene and diesel were obtained from NNPC (Nigerian National Petroleum Corporation) depot whereas the aviation fuel was got from CITA Company at Ibom International Airport, both which are located in Akwa Ibom State, Nigeria. Other materials utilized were nine pieces each, of stainless spatula, stainless pipe (with conical base at one end with an opening to aid combustion and a stainless canopy at the other end to trap the spatula), stainless vessel, glass rod, rigid hollow tube (of diameter 0.0035m made of non-electrical conducting material), Also used in this study were compressors, terminal leads, mercury-in-glass thermometer (-10°C to 100°C), digital multimeter (DT9205A), decade resistance box (RB308), centre-zero galvanometer, College power supply unit, tapping key, density bottles, digital voltmeter, digital ammeter, digital weighing balance (S.METTLER – 600g), Wheatstone Bridge, absorber, clean bottle.

3.2. Procedure for production of the soot

Mass density, each, of the pure kerosene, diesel and aviation fuel, as obtained, was first determined. A reasonable quantity of kerosene was poured into one of the stainless vessels and lit up and made to catch fire using matches. The stainless pipe (with the vent to allow combustion) was quickly inverted on it (to cover it) while a stainless canopy was placed about 2cm above the open end of the stainless pipe. The set-up was kept in a location safe for combustion. The kerosene was allowed to burn completely until the fire completely died out, while the soot got deposited at the inner surface of the canopy. The system was allowed to cool.

The stainless pipe was carefully removed with the canopy and placed in another stainless vessel with a wider surface area to allow for the removal of the layer of soot formed inside the pipe and on the surface of the canopy using a stainless spatula and a clean dry glass rod. The soot collected was stored in a dry clean bottle, covered and labelled for proper identification. The procedure was repeated separately for pure diesel and pure aviation fuel using dry clean bottle in each case. The procedure was again repeated for kerosene-diesel mixtures as well as aviation fuel- diesel mixtures. For each category of mixtures, the diesel content was varied at 25%, 50% and 75% by volume.

3.3. Procedure for preparation of soot cylinder

Each set of soot was packed into a separate dry and clean rigid hollow non-electrical conducting tube of 0.0035 m internal diameter and then after compressed at the same rate for two weeks. The correct identification tag was seriously observed. Each tube with the compressed soot was carefully cut into five different lengths. Each end of a soot pellet was attached a terminal lead. That was done for each of the cylinders.

3.4. Procedure for determination of electrical resistivity of the soot samples

Firstly, measurements of electrical resistance for each length of the as-prepared samples were performed. The methods employed were Wheatstone Bridge, Ohm's law, and use of multimeter as described in details elsewhere [32]. The results were recorded and the mean resistance value for each length was calculated. Secondly, the mean resistance values obtained were plotted against the corresponding length in each case. From the slope of each plotted graph, the electrical resistivity was deduced using equation 4. Then after, the electrical resistivity values were plotted against the proportions of mixtures constituents. All measurements in this work were taken at 28°C .

Table 1. Particulars of the samples

Combustible fluid used	Mass density of the fluid (kgm^{-3})	Sample code
Kerosene	831	K
Diesel	863	D
Aviation fuel (Jet A.1)	815	A
Kerosene-Diesel Mix.	NF	K-D
Aviation fuel-Diesel Mix.	NF	A-D

*NF = Not fixed (as it depends on the proportions of the mixture constituents)

4. Results

The descriptions of the sample materials are presented in table 1. Also, table 2 shows the electrical resistance values obtained and their computed mean values for kerosene-diesel soot samples. Similarly, table 3 shows the results obtained in the case of aviation fuel-diesel soot samples. The calculated values of electrical resistivity of the soot samples are registered in table 4.

Table 2. Results of the measurements performed on the Kerosene-Diesel soot samples used

Soot sample Code	Sample Length, L (m)	Measurement method and electrical resistance value (in Ω) obtained			Mean value of the electrical resistance, $R(\Omega)$
		Wheatstone Bridge	Ohm's law	Digital multimeter	
K0%-D100% (Pure Diesel)	0.005	158.2	163.4	170.0	163.9
	0.007	252.6	260.0	258.4	257.0
	0.010	362.1	371.2	374.0	369.1
	0.012	440.2	438.5	436.2	438.3
	0.015	541.4	554.1	549.1	548.2
K25%-D75%	0.005	296.4	306.8	298.6	300.6
	0.007	394.2	400.4	400.0	398.2
	0.010	570.6	572.3	564.2	569.0
	0.012	621.2	688.0	684.0	664.4
	0.015	848.2	864.1	853.1	855.1
K50%-D50%	0.005	346.1	364.1	350.0	353.4
	0.007	494.9	510.4	520.3	508.5
	0.010	698.2	701.2	704.4	701.3
	0.012	834.2	840.0	846.3	840.2
	0.015	989.1	1003.2	998.2	996.8
K75%-D25%	0.005	6822.4	6610.3	6921.3	6784.7
	0.007	9961.1	11301.4	10823.1	10595.2
	0.010	12506.3	14111.2	13920.3	13845.9
	0.012	13862.1	15126.6	15940.7	14843.1
	0.015	19826.3	21233.2	20814.4	20624.6
K100%-D0% (Pure Kerosene)	0.005	9418.3	9624.5	9810.2	9617.7
	0.007	13404.4	13516.3	13421.0	13447.2
	0.010	18711.7	20006.9	19012.4	19243.7
	0.012	20018.2	9	23120.1	21446.6
	0.015	27140.3	21201.6	32511.1	29685.8

Table 3. Results of the measurements performed on the Aviation Fuel-Diesel soot samples used

Soot sample code	Sample Length, L (m)	Measurement method and electrical resistance value (in Ω) obtained			Mean value of the electrical resistance, $R(\Omega)$
		Wheatstone Bridge	Ohm's law	Digital multimeter	
A0%-D100% (Pure Diesel)	0.005	158.2	163.4	170.0	163.9
	0.007	252.6	260.0	258.4	257.0
	0.010	362.1	371.2	374.0	369.1
	0.012	440.2	438.5	436.2	438.3
	0.015	541.4	554.1	549.1	548.2
A25%-D75%	0.003	189.7	188.4	172.7	183.6
	0.005	222.2	216.8	233.3	224.1
	0.006	262.5	260.1	263.4	262.0
	0.008	320.4	348.2	396.7	355.1
	0.010	363.2	360.3	401.1	374.9
A50%-D50%	0.003	195.2	203.4	197.5	198.7
	0.005	268.8	270.8	270.1	269.9
	0.006	321.4	324.9	325.1	323.8
	0.008	432.0	432.7	430.7	431.8
	0.010	538.5	540.9	540.3	539.9
A75%-D25%	0.003	275.4	333.3	321.7	310.1
	0.005	285.4	354.8	350.2	330.1
	0.006	369.2	378.7	424.2	390.7
	0.008	451.6	531.3	515.3	499.4
	0.010	590.1	690.0	671.0	650.3
A100%-D0% (Pure Aviation fuel)	0.003	535.7	662.4	691.5	629.9
	0.005	706.5	710.3	754.2	723.8
	0.006	782.6	882.2	921.0	861.9
	0.008	963.9	966.3	969.5	966.5
	0.010	1000.0	1312.5	1288.0	1200.2

Table 4. Electrical resistivity values of the soot samples

Kerosene-Diesel soot samples		Aviation fuel-Diesel soot samples	
Sample code	Electrical resistivity, ρ (Ω m)	Sample code	Electrical resistivity, ρ (Ω m)
K0%-D100%	0.351	A0%-D100%	0.351
K25%-D75%	0.546	A25%-D75%	0.404
K50%-D50%	0.662	A50%-D50%	0.524
K75%-D25%	13.011	A75%-D25%	0.634
K100%-D0%	18.387	A100%-D0%	1.251

5. Discussion

Observing from tables 2 and 3 without regard to any particular method of measurements, the electrical resistance of the soot increases with increasing lengths of a sample. Further observation shows that the resistance values for the soot obtained from the mixture of kerosene and diesel fuel is dependent on the ratio of the constituents in the mixture, with the resistance increasing with increase in the proportion of kerosene, while decreasing with increase in the proportion of diesel fuel.

Comparing the resistance values generally, in tables 2 and 3, it can be seen that for soot obtained from combustion of the aviation fuel, the resistance values, irrespective of the method applied, are far lower than those of soot from pure kerosene (as got from the suppliers and used in this study) but higher when compared with the values for soot from the pure diesel. Electrical resistance values for the soot samples from A-D at various proportions are equally lower than the values obtained for the soot samples from their K-D counterparts.

Figure 1 shows the arrays of mean electrical resistance values against the length of the soot for pure samples of kerosene, diesel, and aviation fuel, as well as K-D samples and A-D samples. In all the cases, the graphs depict a positive linear relationship between the mean electrical resistance and length of the soot samples.

It can be observed from table 4 that the diesel, kerosene, and aviation fuel used in this work have electrical resistivity value of $3.51 \times 10^{-1} \Omega$ m, $1.84 \times 10^{-1} \Omega$ m, and 1.25Ω m respectively. For K-D samples at 25%, 50% and 75% content of the diesel, the results obtained are $1.30 \times 10^{-1} \Omega$ m, $6.62 \times 10^{-1} \Omega$ m and $5.46 \times 10^{-1} \Omega$ m respectively. These values clearly differ from those obtained for the A-D samples at the same diesel proportions as content. With respect to the results recorded in the case of K-D samples, the percentage differences in the electrical resistance values at 25%, 50% and 75% of the diesel content are, respectively, 95.1%, 20.8% and 26.0%.

Figure 1. Plots of mean electrical resistance against length for soot samples (a) pure kerosene, diesel, and aviation fuel, (b) kerosene-diesel mixtures, (c) aviation fuel-diesel mixtures

The variation of electrical resistivity with the proportion of constituents of fluid mixtures combusted to have the K-D and A-D soot samples is illustrated in figure 2. Analysis of the figure reveals that the electrical resistivity of K-D mixture relates non-linearly with percentage of their contents. In other words, the figure expresses non-linear relationship between electrical resistivity of soot obtained by combustion of kerosene, diesel and their various percentage mixtures. The same is applicable in the case of the relationship illustrated in the plot for electrical resistivity of the soots from the A-D mixtures.

Comparatively, soot produced by combustion of pure diesel fuel has less resistivity value, indicating higher conductivity than soot obtained from the burning of aviation fuel whereas soot got from the combustion of kerosene exhibits higher electrical resistivity value than the former. This means that soot from kerosene burning is of lower electrical conductivity value than the soot of diesel fuel. Considering the range of electrical resistivity values of our research samples in this work, it suggests that the soots from combustion of diesel, kerosene, aviation fuel and their allied mixtures, fall under semiconductor. This is strongly supported by McGraw-Hill (2005) [17] classification of semiconductor as having electrical resistivity range to be approximately between $10^{-4}\Omega\text{m}$ to $10^5\Omega\text{m}$. However, Schuetz and Frenklach (2002) [9] gave $10^{-5}\Omega\text{m}$ to $10^3\Omega\text{m}$ depending on temperature, as the range of electrical resistivity value of a typical semiconductor. This is equally in support of the argument in favor of the classification of our soot samples as semiconductors. It further suggests that the energy gap between a filled band and the next is extremely small. According to (Schuetz and Frenklach 2002) [9], there exists lower resistivity in a semiconductor as temperature increase empowers more electrons to enter into the empty band.

Figure 2. Variation of electrical resistivity of soot samples with percentage of their constituents for: (a) K-D mixtures, (b) A-D mixtures

Our result is without doubt correct as soot is carbon and carbon such as graphite is listed as a with negative temperature coefficient of electrical resistance. Our test samples, though not investigated for temperature coefficient of resistance, can be considered to have negative temperature coefficient, since soots formed by combusting kerosene, diesel fuel and aviation fuel are species of carbon.

6. Conclusion

It is obvious that when kerosene, diesel and aviation fuel (Jet A.1) are combusted, soot is formed. Equally, when kerosene and diesel are mixed in various percentages of each component or aviation fuel (Jet A.1) and diesel are mixed in various proportions of each constituent, soot is also formed. The soot so formed in each case has its electrical resistivity value depending on the fuel combusted. In the case of the mixtures, the electrical resistivity value is determined by the dominant component. Soots formed by combusting kerosene, diesel, aviation fuel (Jet A.1) and their respective mixtures have electrical resistivity values ranging from $3.516 \times 10^{-1}\Omega\text{m}$ to $1.836 \times 10^{-1}\Omega\text{m}$. This information is very useful for the purpose of formation of soot with a required electrical resistivity value for electronics and electrical purposes. The information can also be very useful for quality analysis of petroleum products with reference to adulteration and for archeological studies.

This work has provided a database on the electrical resistivity values of soot formed as a result of combustion of some fuels and their mixtures for probable utilization by electrical, electronics and petroleum industries. There has been no report on such database in the literature, thus making this research work a novel.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1.] Blanquart, G. Pitsch, H., Modeling soot formation in kerosene and fuel surrogates. Combustion western States station of the combustion Institute Spring meeting, University of Southern California Paper #08S-31(2008) 1 – 15.
- [2.] Colket, M. Edwards, T. Williams, S. Cermansky, N. Miller, D. Egolfopoulos, F. Lindstedt, P. Seshadri, P. Dryer, F. Law, C. Friedn, D. Lenhart, D. Pitsch, H. Sarafim, A. Smooke, M. Tsang, W., Development of an experimental database and kinetic models for surrogate jet fuels, in: 45th AIAA Aerospace sciences meeting and exhibit, Reno, Nevada, Jan. (2007) 8 – 11.
- [3.] Zhao, B. Yang, Z. Johnston, M.V. Wang, H. Wexler, A.S. Balthasar, M. Kraft, M., Measurements and numerical simulation of soot particle size distribution functions in laminar premixed ethylene-oxygen-argon flame, *Combust. Flame* 133(2003) 173 – 188.
- [4.] Zhao, B. Yang, Z. Li, Z. Johnson, M.V. Wang, H., Particle size distribution function of incipient soot in laminar premixed ethylene flames: effect of flame temperatures. *Proc. Comb. Inst.* 30(2005) 1441 – 1448.
- [5.] Koylu, U.O. Faeth, G.M. Farias, T.L. Carvalho, M.G., Fractal and projected structure properties of soot aggregates. *Combust. Flame*. 100(1995) 621 – 633.
- [6.] Jensen, K.A. Suo-Antilla, J.M. Blevins, L.G., Measurement of soot morphology, chemistry and optical properties in the visible and near-infrared spectrum in the flame zone and overfire region of large JP-8 pool fires. *Combust. Flame* 179(2007) 2453 – 2487.
- [7.] Blanquart, G. Pepiot-Desjardins, P. Pitsch, H., Chemical mechanism for high temperature combustion of engine relevant fuel with emphasis on soot precursors. *Combustion and Flame* 156(3)(2008) 588 – 607.
- [8.] Appel, J. Bockhorn, H. Frenklach, M., Kinetic modelling of soot formation with detailed chemistry and physics; Laminar premixed flames C₂ hydrocarbons. *Combust. Flame*, 121(2000) 122 – 136.
- [9.] Schuetz, M. Frenklach, M., Nucleation of soot: Molecular dynamics simulations of pyrene dimerization *Proc. Comb. Inst.* 29(2002) 2307 – 2314.
- [10.] Frenklach, M. Wang, H., Detailed modeling of soot particle nucleation and growth, *Proc. Comb. Inst* 23(1991) 1559 – 1566.
- [11.] Lam, N.I. Chen, Y. Weyant, C. Venkataraman, C. Sadavavte, P. Johnson, M.A. Smith, K.R. Brem, B.T. Arineitwe, J. Ellis, J.E. Bond, T.C., Supporting information household light makes global heat: High black carbon emissions from kerosene wick lamps, (2012) S1 – S31.
- [12.] International Finance corporation and the world bank, IFC / WB Quantitative Assessment – Kenya(2008)
- [13.] Uganda Bureau of statistics, Uganda National Household survey 2009 / 2010 Abridged Report, Kampala(2010)
- [14.] National Bureau of Statistics Nigeria, Nigeria general household survey, 3rdEdn, Federal Government of Nigeria Abuja(2006).
- [15.] Minnesota Population Center, Integrated public use microdata series international: Version 6.1 [Machine readable dataset] University of Minnesota; Minneapolis, (2011).
- [16.] Weaver, E.E., Encyclopedia of science and technology Vol. 2, McGraww-Hill, London(1971).
- [17.] McGraw-Hill, McGraw-Hill Concise Encyclopedia of science and technology. 5thEdn, McGraw-Hill, New York(2005).
- [18.] Morris, N.M., Mastering electronics and electrical calculations, Macmillan Press Ltd, London, (1996).
- [19.] Scherz, P. Monk, S., Practical electronics for inventors, 4thEdn. McGraw-Hill Education, New York, (2016).
- [20.] Morris, N.M., Digital electronic circuits and systems. Macmillan Press Ltd, London, (1974).
- [21.] Slimark, S. Djordjevic, N., Dam site engineering geophysics in Yugoslavia. *First Break* 5(5)(1987) 161 – 171.
- [22.] Ojo, J.S. Ayangbesan, T.A. Olurufemi, M.O., Geophysical survey of a dam site: A case study. *J. Min. Geol.* 26(2)(1990) 201 – 207.
- [23.] Aina, A. Olurufemi, M.O. Ojo, J.S., An interpretation of aeromagnetic and electrical resistivity methods in dam site investigation, *Geophysics*, 61(2)(1996) 349 – 356.
- [24.] Badmus, B.S. Oyedele, I. Ojelabi, E.A., Electrical resistivity soundings to determine surface contamination in the vicinity of refuse dump. *Glob. J. Pur. Appl. Sci.* 7(3)(2001) 477 – 482.
- [25.] Olurufemi, M.O. Ojo, J.S. Sonuga, F.A. Ajayi, O. Oladapo, M.I., Geophysical investigation of karkarku earth dam Embankment. *Glob. J. Pur. Appl. Sci.* 6(1)(2000) 117 – 124.
- [26.] Griffiths, D.H. Barker, R.D., Two-dimensional resistivity imaging and modelling in areas of complex geology. *J. Appl. Geophys.* 29(1993) 211 – 226.
- [27.] Noel, M. Walker, R., Development of an electrical tomography system for imaging archeological structures. *Archaeometry* 32(1970) 767 – 776.
- [28.] Theraja, B.L. Theraja, A.K., A textbook of electrical technology, 23rd Revised Edn, S. Chand and co ltd, New Delhi, (2003).
- [29.] Theraja, B.L., Basic electronics, solid state, multicolour illustration, Edn, S. Chand Ram Nagar, New Delhi, (2008).
- [30.] Young, H.D. Freedman, R.A., University Physics, Pearson International Edition, 12thEdn, Pearson Addison Wesley, San Francisco, (2008).
- [31.] Nung, G.J., Electronics in our world: A survey. Englewood Cliffs, Prentice-Hall, (1972).
- [32.] Gupta, J.P., A course in Electronics and Electrical Measurements and Instrumentation, 13th Edn., S. K. Kataria & Sons, Daryagary, New Delhi, (2008).

How to Cite This Article

Etuk, S.E., Emah, J.B., Robert, U.W., Agbasi, O.E., Akpabio, I.A., Comparison of Electrical Resistivity of Soots Formed by Combustion of Kerosene, Diesel, Aviation Fuel and their Mixtures, *Brilliant Engineering*, 3(2021), 6-10.
<https://doi.org/10.36937/ben.2021.003.002>