Neutron Activation Analysis of Some Ceramic Insulators used in the Manufacture of Transformers and Household Appliances.

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ABSTRACT

A study is carried out on the concentrations of constituent (major, minor, and trace) elements present in ceramic insulators and their effects on its insulative properties. In carrying out the analysis, the best and most convenient method being the Instrumental Neutron Activation Analysis (INAA) otherwise known as Non-Destructive Neutron Activation Analysis (NDNAA) was adopted.

Ceramic insulators were obtained, crushed to powdery form and samples prepared for INAA. A typical soil sample was also obtained for comparison between the raw product- clay and the finished/processed products ceramics. 250mg of the samples were fed in to the nuclear reactor by means of pneumatic transfer with the aid of rabbit capsules. The irradiated samples have been analyzed and the following elements identified: Al, Ti, Ca, Mg, K, Na, V, Mn, Dy, Sc, Zn, La, Sm, Co, Ta, Th, Rb, Ce, Hf, Fe, Yb, Cs, Sb, As and U. The elements which enhance the insulative properties of the ceramic insulator have been highlighted and are as follows Al, Fe and Ti as major elements; while Zn and Mn are minor elements. There have been higher concentrations found in the soil than in the other ceramics as seen in Al from the following results: Electric fuse (0.014 $\pm$ 0.007), Socket fuse (0.0219 + 0.0006), Ceramic (0.234 + 0.003) and soil (0.3972 + 0.004); indicating that processing of the raw materials affect the concentration of the elements that have positive effect on the insulative properties of the ceramic insulator. The results and technique compared with that of Oladipos who had a total of 22 elements from 7 different clay samples indeed showed that NAA is effective method of elemental analysis.

(Keywords: neutron NAA, non-destructive, INAA, ceramic insulators, trace, major and minor elements).

INTRODUCTION

Technology is the centre of industrialization. In the area of electronics and communications, ceramics have played a vital role. Indeed, ceramics has advanced far beyond its beginnings in clay pottery as the term once referred only to clay-based materials. However, new generations of ceramic materials have tremendously expanded the scope and number of possible applications. Many of these new materials have a major impact on our daily lives and on our society.

Ceramic materials are inorganic compounds, usually oxides, nitrides, or carbides. The bonding is very strong - either ionic or network covalent. Many adopt crystalline structures, but some form glasses. The properties of the materials are a result of the bonding and structure.

Ceramics can withstand high temperatures, are good thermal insulators, and do not expand greatly when heated. This makes them excellent thermal barriers, for applications that range from lining industrial furnaces to covering the space shuttle to protect it from high reentry temperatures (Peterson and Peterson, 2003).

Ceramic materials have a wide range of electrical properties. Hence, ceramics are used as insulators, some are capacitors, others semiconductors in electronic devices. Piezoelectric materials can convert mechanical pressure into an electrical signal and are especially useful for sensors. Fiber optic cable is rapidly replacing copper for communications, as optical fibers can carry more information for longer distances with less interference and signal loss than traditional copper wires.

Ceramics such as aluminum oxide (Al_2O_3) do not conduct electricity at all and are used to make insulators. Stacks of disks made of this material are used to suspend high-voltage power lines from transmission towers. Similarly, thin plates of aluminum oxide, which remain electrically and chemically stable when exposed to high-frequency currents, are used to hold microchips. (Grim et al., 1947)

Other ceramics make excellent semiconductors. Small semiconductor chips, often made from barium titanate ($BaTiO_3$) and strontium titanate ($SrTiO_3$), may contain hundreds of thousands of transistors, making possible the miniaturization of electronic devices.

Thin insulating films of ceramic material such as barium titanate and strontium titanate are capable of storing large quantities of electricity in extremely small volumes. Devices capable of storing electrical charge are known as capacitors. Miniature capacitors are formed from ceramics and use in televisions, stereos, computers, and other electronic products.

Ferrites (ceramics containing iron oxide) are widely used as low-cost magnets in electric motors. These magnets help convert electric energy into mechanical energy. In an electric motor, an electric current is passed through a magnetic field created by a ceramic magnet. As the current passes through the magnetic field, the motor coil turns, creating mechanical energy.

Unlike metal magnets, ferrites conduct electric currents at high frequencies (currents that increase and decrease rapidly in voltage). Because ferrites conduct high-frequency currents, they do not lose as much power as metal conductors do. Ferrites are also used in video, radio, and microwave equipment. Manganese zinc ferrites are used in magnetic recording heads, and bits of ferric oxides are the active component in a variety of magnetic recording media, such as recording tape and computer diskettes (Grim et al 1947).

The performance of ceramic insulators is closely linked to the raw materials used for its formulation and the processing technology employed. The primary objective of this work is to determine and identify the various major, minor and trace elements such as Na, K, Sc, Ti, Ga, Co, Rb, Sr, Zr, Lu, tm, Yb, Th, Gd, Eu, U, Cl, Al, Ti, Sm, Nd, Dy, Ir, Ag, Sb, La, Ba, Ce, Mo, and Ho present in the samples of ceramic insulators used in the manufacture of indoor electric equipment. The concentrations will also be determined as well as their effect on the energy band spectrum of insulators. The instrumental neutron activation analysis techniques will be employed.

Ceramics are materials made of pottery such as clay. It is the art of moulding an object from clay such as porcelain or plaster of Paris. They are insulators and hence don't support electricity. The characteristic of clay is seen in its naturally pliable, yet rigid and resilience when exposed to high temperature. It undergoes diverse processes of shaping, moulding, glazing and firing to become an object of beauty and admiration (Peterson and Peterson, 2003)

Ceramics have application in domestic, industrial and for commercial purposes. In the industry, ceramics are employed for reasons such as production of ceramic materials to construction of scientific and industrial components. These newly produced materials are heat resistant, very hard and can be used in electrical conductance. Ceramic find commercial application through production of materials used in sanitary ware, walls and tiles. They can also be used in recreational purposes and for relaxation.

Insulators are basically materials and objects that do not transmit current or allow electrons flow through them. Electronically speaking, insulators have larger band gap or energies that electrons must occupy or attain to enable the flow of current. The charges within insulators are bound hence no free movement of charge resulting in very high resistivity. Examples are diamond and rubber.

Conductors are materials or object that enable the flow of current or electricity through them without any resistance. There are free electrons inside a conductor moving almost at the speed of light ($10^8 ms^{-1}$). Resistance increases as temperature increases thereby increasing the kinetic energy and these results in greater collision between the atoms. The consequent increase in vibration of the nucleus leads to greater collision. There is low resistivity given by the expression:

$$R = \rho L/A \quad \textbf{(1)}$$

Electronic equipments are made up of semi conductor fabrics which are vital in sophisticated technology and contemporary or present day devices ranging from cellular phones, DVD, VCD players to computers.

Neutron Activation Analysis (NAA)

This is simply a multi element method for the trace element determinations (0.01%) even though minor and major elements may be determined some applications. G. Hevesy and Levi, developed the Analysis as far back as 1936 strictly for the analysis of Dy using isotopic source, but it did not become a practical method of analysis until the development of the nuclear reactor.

Neutron Activation Technique guarantees high standard of sensitivity in detecting major components of substances even as far as determining the trace elements present in a sample of water, sand, leave, ceramic, etc. The speed at which this occurs is also an added advantage. Currently it has become easily accessible by virtue of advanced technological developments of portable and affordable nuclear generators. The machinery entails pneumatic systems, which conveys sample from the site of irradiation to the laboratory; it also provides radiochemical modes of separation and entirely instrumental methods. The latter makes it easy to detect an element without chemical separations even at the extreme high speeds.

In accordance to the law of radioactive decay, the number of nuclei which disintegrates per unit time (-dN/dt) is proportional to the total number of nuclei, N

$$-\frac{dN}{dt} = -\lambda N \qquad \textbf{(2)}$$

where λ is the decay constant and characteristic of the nuclei.

Integrating the solution of the above equation gives:

$$N_2 (t) = \Phi\sigma_1 N_1/\lambda_2 (1 - \exp(-\lambda_2 t)) \qquad \textbf{(3)}$$

This is the basic NAA equation (Jonah, 1993).

Instrumental Neutron Activation Analysis (INAA) technique has been widely employed for the determination of major, minor and trace elements in clays, pottery and other ceramics (Oladipo, 1992, 2003). Oladipo (1992) was able to identify quantitatively 22 element concentrations: Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Rb, La, Ce, Sm, Eu, Dy, Hf, Ba, Th, and U in the clays gathered from diverse lignite associated clay beds. The samples were of similar geological origin; however, have been obtained from different lignite associated clay beds. An appropriate algorithm was devised to classify the samples and the analysis proves the fact that NAA is competent in establishing noteworthy outcomes.

NAA of minor elements is an appropriate technique for the analysis of geological samples of diverse matrices. (Oladipo et al., 1989). Much research has been carried out on the ability of NAA to detect tiny differences in the make-up of clays having same geological origin. Oladipo's work used a 200g sample, irradiated in a reactor at a thermal neutron flux of 2 x 10^{12} ncm^{-2} s^{-1}; alongside suitable standards.

METHODOLOGY

Sample Collection

First, different samples of ceramic insulators were collected. The first ceramic insulator was obtained from the Power Holding Company of Nigeria. This is a heavy brownish oval object found in the interior of transformer units. Next, the House hold appliances were purchased from the Wuse market in Abuja. These included adaptors, extension box and wire, and electric cable used in wiring homes and offices. Diagrams are seen below. Care was taken to eliminate sample contamination. This includes the method of packaging, storage, and conveyance used.

It is important that the samples prepared are in powdery format so as to enable sufficient area exposure to the nuclear reactor. It could be done locally but most efficiently industrial from research centres such as NMDC Jos. The devices were fed into a machine that crushed it to powder and flakes. The powders were of the order of a few microns. The specification of the powered transformer ceramic insulator is of the order of -35μm. This implies that after it was grinded, it was then filtered through a sieve having holes of the order of 0.035 meshes. Specification of Socket fuse (adaptor) powder is -35μm or 0.035 mesh and extension box powder is +1mm. The electric fuse when grinded came out in tiny flakes likewise extension wire. The copper wire came out in the form of tiny bits -1mm long.

Figure 1: Wall Socket.

Figure 2: Extension Boxes and wire

Figure 3: Adaptor Sideway View.

Figure 4: Adaptor Top View.

Sample Preparation

This consists primarily of weighing and packaging. Any chemical treatment, which could lead to the contamination of sample by impurities from the reagents, is completely avoided as well as the surface of solid samples, cleaned to get rid of surface impurities. The sample aliquots of the standard approximately 200 – 250 mg were weighed and wrapped in polyethylene films. The polyethylene films and rabbit capsules were cleaned by soaking in 1:1 HNO_3 (nitric acid) for 3 days and washed with deionized water. Next, blank concentrations of all the elements of interest were investigated and using the adopted procedures and were found to be less than limits of detection (Jonah et al, 2006). The polyethylene films and rabbit capsules were soaked in 1:1 HNO_3 to eliminate every contamination.

Sample Analysis

In short irradiation, each of the samples were parceled, sealed in 7cm^3 rabbit capsules and sent for irradiation one after the other in one of the outer irradiation channels. The neutron spectrum in the outer channel B is soft having a flux of 2.5 x 10^{11}n/cm^2s and irradiation period of 600sec. The outer irradiation channel was chosen so as to eradicate corrections, which arise from nuclear interferences caused by threshold reactions notably Mg in the presence of Al; Al in the presence of Si; and Na in the presence of P. All these are as a result of the closeness of the inner channels of the MNS reactors to the core leading to the relatively higher ratio of fast to thermal neutrons. The long irradiation entailed wrapping samples in polyethylene films and stack packing each inside the 7cm^3 rabbit capsule and heat-sealed for irradiation. The samples are irradiated for 6 hours in any of the small inner irradiation channels, which are A1, B1, B2 and B3. This enables exposure to the maximum value of thermal neutron flux of 5 x 10^{11}n/cm^{2}s. The flux is kept constant by monitoring the neutron flux reading from of a fission chamber connected to the microcomputer-controlled room. After the samples have been irradiated they are retrieved via the same pneumatic transfer of the rabbit to the control chamber where they are collected and kept in a glass chamber.

Measurement of Gamma Rays

The PC-based gamma-ray spectrometry set-up performs the radioactivity of the induced radionuclides. After the short irradiation, there is a waiting time of 2 to 15 minutes, followed by the first bit of counting which was carried out for ten minutes. The samples are placed on a plexi-glass sample holder designated H2 which refers to the source detector geometry of 5cm. This is depicted as S1. The second lap of counting is also carried out for 10 minutes after irradiation and depicted as S2. The waiting period in this case is as long as 3-4 hours. Samples are counted on a plexi-glass plated denoted H1 which refers to a source detector geometry of 1cm.

For long irradiation, the first lap of counting was carried out after a waiting period of 4-5 days for duration of 30minutes. This Long irradiation is termed L1 and is carried out using the H1 holder. The second lap of counting is carried out after a cooling period of 10-15 days for duration of 60minutes. This termed as L2 and samples counted using plexi-glass holder H1. With the aid of gamma ray spectrum software known as WINSPAN 2004, the gamma rays of product radionuclides can be identified by their energies, as well as quantitative analysis of their concentrations are obtained. The spectrums have been acquired by virtue of the MAESTRO soft ware (Multi channel analyzer). Found below is a diagram of the energy spectrum of few of the samples depicting different energy levels as displayed by the PC using the WINSPAN Software®.

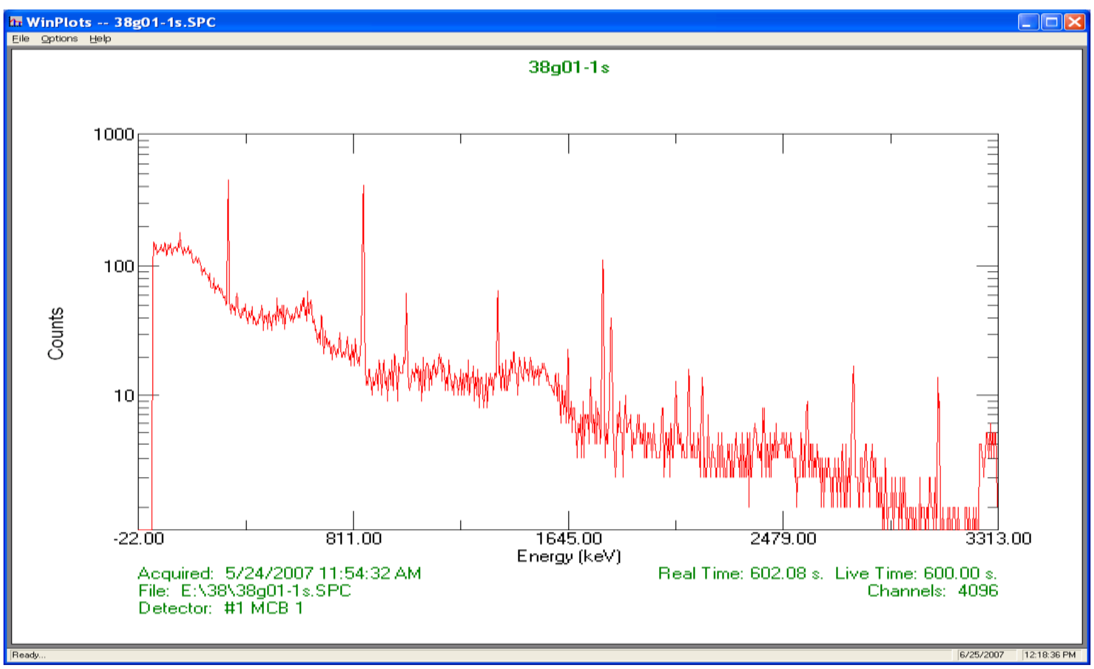

Figure 5: First Irradiation.

Radiation Protection and Management of Irradiated Samples

Safety taken into account while conducting the analysis is that of the personnel and disposal of the irradiated sample after counting is completed. There are warning light signals that automatically comes on whenever the reactor is operation or turned on. There are also the safety precautions taken by the scientists and engineers by wearing Lab coats, compulsory and strict restriction of pregnant women into the vicinity.

Approximately 250mg of the powdered sample is wrapped in polyethylene sheet, and further encapsulated in a polyethylene vile and via pneumatic transfer system; it is placed inside the reactor. The operator stays in the fission chamber connected to the microcomputer-controlled room throughout the irradiation process where he operates the reactor thus shielding him from possible radiations. After irradiation, the irradiated samples and standards are retrieved via same pneumatic transfer thereby ensuring safety of personnel carrying out the analysis. Gamma dosimeters are worn to ensure monitoring of the gamma dose induced in the sample. The sample vial is only opened after dose is below 30µSvhr^{-1} and gamma–ray counting is performed. This is considered safe value. After the analysis is completed, the irradiated samples and standards are packed together in polyethylene sheets and put in a lead container for disposal.

RESULTS AND ANALYSIS

Table 1: Concentrations of Elements for Socket Fuse, Electric Fuse, Ceramics and Karu Soil.

Elements	Concentrations			
	Socket Fuse	Electric Fuse	Ceramics	Karu Soil
Al (%)	0.014 ± 0.007	0.02194 ± 0.0006	0.234 ± 0.003	0.3972 ± 0.004
Ti (ppm)	9166 ± 375.81	10510 ± 400.0	BDL	9821 ± 756.22
Ca (%)	0.1336 ± 0.016	0.073 ± 0.011	BDL	0.077 ± 0.014
Mg (ppm)	8809.0 ± 1021.8	5321 ± 931.18	181400 ± 4535.0	BDL
Dy (ppm)	BDL	7.117 ± 0.48	BDL	BDL
K (%)	0.013 ± 0.0017	0.014 ± 0.0017	NA	0.1937 ± 0.004
Cl (ppm)	-	-	NA	-
Na (ppm)	2198 ± 10.99	1609 ± 9.65	NA	2633 ± 13.17
V (ppm)	4.369 ± 0.813	5.756 ± 1.14	17.30 ± 2.80	42.78 ± 4.28
Mn (ppm)	67.38 ± 1.15	167.2 ± 1.67	1708 ± 8.54	615.3 ± 3.70
Br (ppm)	-	-	NA	-
La (ppm)	BDL	4.086 ± 0.31	NA	63.90 ± 0.58
Sm (ppm)	0.6603 ± 0.042	5.589 ± 0.25	NA	10.18 ± 0.45
Sc (ppm)	0.5616 ± 0.09	1.008 ± 0.16	BDL	14.39 ± 0.63
As (ppm)	2.942 ± 0.029	BDL	NA	BDL
Yb (ppm)	BDL	13.00 ± 1.29	NA	BDL
U (ppm)	BDL	15.6 ± 1.14	NA	18.00 ± 4.90
Cr (ppm)	BDL	-	BDL	-
Fe (%)	0.0712 ± 0.007	0.1912 ± 0.01	0.022 ± 0.004	0.528 ± 0.013
Co (ppm)	BDL	3.013 ± 0.77	BDL	22.56 ± 1.173
Zn (ppm)	939.1 ± 41.32	1275 ± 54.83	BDL	144.2 ± 25.52
Rb (ppm)	BDL	BDL	BDL	116.9 ± 15.67
Sb (ppm)	1.430 ± 0.16	2.514 ± 0.22	BDL	BDL
Cs (ppm)	2.007 ± 0.38	BDL	BDL	BDL
Ba (ppm)	-	-	BDL	-
Ce (ppm)	15.81 ± 2.86	BDL	BDL	BDL
Eu (ppm)	BDL	BDL	BDL	BDL
Lu (ppm)	BDL	BDL	BDL	BDL
Hf (ppm)	34.67 ± 0.80	184.1 ± 2.21	BDL	BDL
Ta (ppm)	BDL	103.5 ± 1.24	BDL	BDL
Pa (ppm)	-	-	BDL	-
Th (ppm)	BDL	3.923 ± 0.54	-	355.1 ± 8.17

Soil samples for Karu were analyzed to simulate clay, the raw material usually used for making ceramic insulator as well as to compare the elemental composition of the raw material with what is obtainable in the insulators. The result of the experimental determination is given in Table above.

The table shows that six elements are present as major elements for socket and electric fuse. These include Al, Ti, Ca, K, Na and Fe. Mg, which constitutes a major element, was determined to be below detection limit. However, the Karu soil is enriched in Al, K, and Fe compared with the Ceramic. Minor elements such as Mn was detected, while Zn was were below detection limit. Two of trace elements Hf and Sb detected in the Ceramic were below detection limit. Rb which was also detected in any of the fuses was present in the Karu soil at trace concentrations. In all, eleven (11) elements were below detection limit in the Karu soil.

Twenty-two elements were analyzed for in the ceramic. Five elements were above detection limit and include Al, Mg, V, Mn, and Fe. While Al, Mg, Mn, and Fe occur as major elements, V was present at trace concentrations. This sample was found to be depleted in such important elements as Ca, Ti, and Zn normally associated with clays.

DISCUSSIONS

Al, Ca, K, and Fe are major elements and thus are present at percentage levels in the socket fuse, electric fuse and in the soil. Ti, Mg, Na are also major elements present in ppm in the soil. Despite the fact that Ca and K elements are present in high amounts in the soil, they do not have positive effects on the insulative properties of the ceramic insulators whereas Al and Ti enhance the insulative properties of the soil. These can be seen in the likes of ceramic insulators such as Aluminium Oxide (Al_2O_3), Ferric Oxide and Magnesium, Zinc Oxide. It is observed from the tabulated results however that the percentage of these elements in the soil is greater than those of the socket fuse and electric fuse. (A = 0.014 0.007, 0.0219 0.0006 as compared with 0.3972 0.004) These particular ceramic insulators are not manufactured directly from Karu soil.

Karu soil is only used to simulate raw material clay. The choice of Karu soil is chiefly due to the fact that Ceramic Company is located in Abuja for manufacture of mainly tiles alongside other pottery centres such as Ushafa Clay Centre, Ladi Kwali Pottery and Giri Pots. Comparing the above concentrations of Al in the ceramic insulators with that of soil, it portrays that there is the possibility of the elemental concentrations being reduced during the process of manufacturing the ceramic products from the raw material soil. Thus, the percentages of these elements are reduced. The same holds true for Ti and Na.

It is observed that the concentrations of magnesium is strangely below detection limit for the soil, this might not apply to the soil, this might not apply to other soils obtained elsewhere as observed from the results of Oladipo. Other elements that enhance the insulative properties of the insulators are Zn and Mn since they make very good ceramic insulators. As is a non-metal hence it also enhances the insulative properties of the ceramic insulators.

The ceramic is a different kind of sample from the others in that it is used in the manufacture of transformers and hence has different make up from the others. This is the reason for having most of the elements below detection limit. Most of the elements in this ceramic type cannot be depicted by the sensitivity of the INAA technique. This could be corrected for in RNAA of XFR (X-ray fluorescence). It is observed that only Al, Ca, V, Mn, and Fe have concentrations. The advantage of these is also seen in insulative ceramics such as Manganese Zinc Ferrite and Aluminium Oxide; that is Mn and Fe will definitely enhance the insulative properties of this ceramic insulator. Some important elements are not available. Most results are not analysed due to the fact that the sample leaked while performing that analysis.

Normally the flux is concentrated on a unit area so as to identify the elements and determine their concentration. Now if the boundary of the flux is exceeded it implies boundary not defined, it could lead to an undefined result. In this case the leakage was outside the reactor, most likely due to cooling there could have been a crack on the capsule thus affecting the results.

Oladipo’s work used a 200g sample, irradiated in a reactor at a thermal neutron flux of 2 x 10 12 ncm-2 s-1; alongside suitable standards. Three diverse regimes were employed in measurements of the elements: Short lived Isotopes (Mg, Al, Ca, Ti, V, Mn, Ba, Eu, U): 10 minute irradiation, thirteen minutes decay and four minute count for sample (2 samples irradiated simultaneously to improve throughout). Comparing his results with this work, it is observed that Mg, Al, Ca, Ti, V, Mn and U are present in the fuse and ceramic samples as well as in the soil. Ba and Eu are absent from these samples.

Intermediate lives isotopes (Na, K, Mn, Dy): ten-minute irradiation, two hour decay and twenty minutes count. Comparing with this analysis, Na, K, Mn and Dy have also been identified.

Long lived Isotopes (Sc, Cr, Fe, Co, Rb, La, Ce, Sm, Hf): Seven-hour irradiation, ten-day decay and two-hour count. Sc, Fe, Rb, La, Ce, Sm and Hf have been analyzed in the fuse and ceramic as well as the soil. Cr is absent from the ceramic and soil samples.

The concentrations of other radionuclides were not reflected because their detection limit is far above that of Instrumental Neutron activation Analysis. Proper packaging and heat-sealing the samples before transferring by pneumatic transfer system into the reactor should be encouraged. Methods of analysis used for specific elements whose detection limit is within range example is Radiochemical Neutron Activation Analysis (RNAA) and XRF (X-ray fluorescence) should be employed.

SUMMARY

The Neutron activation analysis of a ceramic insulator used in the manufacture of Transformer have been carried out and the following radionuclides identified as well as their concentrations determined. Sixteen (16) elements identified are as follows between the ceramic and soil samples: Al, Ti, Ca, Mg, K, Na, V, Mn, Sc, Zn, La, Sm, Co, Th, Rb, Fe, and U. Others such as Lu, Eu, Ba, and Pa are below detection limit whereas Cl and Br were not analyzed. Oladipo (1992) was able to identify quantitatively 22 element concentrations: Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn , Fe, Co, Rb, La, Ce, Sm, Eu, Dy, Hf, Ba, Th, and U in clays gathered from diverse lignite associated clay beds.

Comparing the results Oladipo obtained and that obtained in this analysis it is observed that Cr, Eu, and Ba were not analyzed in the ceramic samples and Karu soil. Silicon, which is a very vital semi conductor element, is not present in this sample due to the fact that it is activated by fast neutrons and as such is far below the detection limit of the INAA. The absence of silicon from the samples has also contributed to the insulative properties of the ceramic insulators.

CONCLUSION

Non Destructive Neutron Activation Analysis has proved to be an effective method of analyzing trace elements in ceramic insulators. More importantly is the fact that the basic major elements which is universally present in soil (clay) samples are clearly identified in percentage concentrations and ppm; as well as the key elements needed to enhance the insulative properties of ceramics such as Al, Fe, Zn, and Mn are also found in moderate quantities.

REFERENCES

1. Alfassi, Z.B. 1990. *Activation Analysis, Volumes I and II*. CRC Press: Boca Raton, FL.

2. De Soete, D., R. Gijbels, and J. Hoste. 1972. *Neutron Activation Analysis*. John Wiley and Sons: New York, NY.

3. Hevesy, G. and H. Levi. 1936. “The Action of Neutrons on the Rare Earth Elements”. *Det. Kgl. Danske Videnskapernes selskab, Matematisk-fysiske meddelelser*. 14:3.

4. Jonah, S.A. 1993. “Applications of Neutron Activation Analysis Technique”. Centre for Energy Research and Training, Zaria, Nigeria. Technical Report. Unpublished.

5. Jonah, S.A., I.M. Umar, M.O.A. Oladipo, G.I. Balogun, and D.J. Adeyemo. 2006. “Standardization of NIRR-1 irradiation and Counting Facilities for Instrumental Neutron Activation Analysis”. Centre for Energy and Research Training, Ahmadu Bello University, Science Department: Zaria, Nigeria. 818-822.

6. Naeem, A. 1987. “Multi-Element Determination in Water by Instrumental Neutron Activation Analysis”. *J. Radioanal. Nucl.Chem. Letters.* 118:79 – 88.

7. Oladipo, M.O.A., A. Adeleye, and S.B. Elegba. 1989. "Establishment of References Materials for Nigerian Using Instrumental Neutron Activation Analysis". Centre for Energy Research and Training CERT Zaria. University Press: Zaria, Nigeria.

8. Oladipo, M.O.A. 1992. "Neutron Activation Analysis of Clay and their Classification for Mineral Prospecting". Centre for Energy Research and Training CERT Zaria. University Press: Zaria, Nigeria.

9. Oladipo, M.O.A. 2003. Establishment of Geological References Materials from Clay Sources: Comparison of Results obtained from Collaborating Laboratories". Centre for Energy Research and Training CERT Zaria. University Press: Zaria, Nigeria.

10. Peterson, S.H. and J. Peterson. 2003. *The Craft and Art of Caly: A Complete Potter's Handbook*. Laurence King Publishing ISBN 1856693546. 22 – 25.

11. Grim, R.E, W.H. Allaway, and F.L. Cuthbert. 1947. "Reaction of Clays with Organic Cations in Producing Refractory Insulation". *Journal of American Society*. April 24, 1947. (Refractories Division, No. 15).

12. Grim, R.E., W.H. Allaway, and F.L. Cuthbert. 1947. "Reaction of Different Clay Minerals with Some Organic Cations. *Journal of American Society*. April 23, 1947 (Refractories Division, No. 10).

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