International Journal of Multidisciplinary Research and Growth Evaluation.

The Prospects and Beneficiation of Solid Mineral Deposits in Kebbi State, Nigeria: A Case Study of Iron Ore Deposit

Evarastics Polycarp [1*], Mahdi Sani Udu [2], Lasisi Shaibu [3], Muyideen Abdulkadir [4], Lasisi Isa OLUSEGUN [5]

[1-3] Department of Metallurgical Engineering Technology, Waziri Umaru Federal Polytechnic, P.M.B 1034, Birnin Kebbi, Kebbi State, Nigeria

[4-5] Department of Mechanical Engineering Technology, Waziri Umaru Federal Polytechnic, P.M.B 1034, Birnin Kebbi, Kebbi State, Nigeria

* Corresponding Author: **Evarastics Polycarp**

Article Info

ISSN (online): 2582-7138
Volume: 04
Issue: 04
July-August 2023
Received: 03-06-2023
Accepted: 23-06-2023
Page No: 498-503

Abstract

According to Nigerian Extractive Industries Transparency Initiative (NEITT) report, the total revenue generated from the solid minerals sector amounted to N33.86 billion in 2013 equivalent to 0.11% of GDP; while in 2014 and 2015 the total revenues were N55.82 billion and N69.2 billion which, are equivalent to 0.33% and 0.55 of GDP respectively. This is a reversal of the historically higher percentage of 5.0% between 1960 -1970 (Ighodalo, 2018). The negligence of the solid minerals sector and total dependence on crude oil has put the Nigerian economy under pressure due to the dwindling prices of crude oil in the international market over the years. The current call for diversification of the economy and the recent determination of the past Government of the Mohammadu Buhari Administration to complete the Ajaoukuta Steel Complex was a right step in the right direction but never saw the light of the day. This paper, therefore, focuses on the prospects and beneficiation of solid minerals deposit in Kebbi State, Nigeria; using iron ore deposit as a case study. The availability of various solid minerals in Kebbi State, if properly harnessed, will boost the Internally Generated Revenue (IGR) of the State; enhance human resource and infrastructural development and will reduce crime in the State due to the activities of the teaming unemployed youths that may culminate in illegal mining banditry, kidnapping and other social vices.

Keywords: Beneficiation, Iron Ore, diversification, Solid Minerals, Reduction Process

1. Introduction

Solid minerals are naturally occurring inorganic substances with definite chemical compositions, crystal structures, and other mineralogical characteristics formed over the years due to geological changes that have taken place on the earth's crust. By providing gainful employment and a rise in national income profits far exceeding the petroleum sector, a well-established and well-managed solid minerals sub-sector will accelerate Nigeria's economic, social, and political fortunes. These minerals will, if harnessed, bring foreign exchange earnings to the nation, supply raw materials for the local industries, build infrastructure and bring prosperity to rural communities where these minerals are found at commercial quantity. Solid minerals have the potential to serve as a panacea for the development of other sectors of the economy, as well as promote oneness rather than ethnic, religious and political discrimination being experienced recently (OSGF, 2021) [24].

There are more than 44 different types of non-oil mineral resources in Nigeria. These include; gold, copper, iron ore, limestone, bitumen, lignite, coal, lead/zinc, gypsum, kaolin, sapphire, granite, laterite, sand, and clay. Despite the abundance and diversity of solid mineral deposits across the 36 States of the Federation, they have not imparted much on the Nigerian economy in recent years due to over-dependence on crude oil.

The neglect of the solid minerals industry has resulted in chaos and the high presence of illegal miners whose activities are marked by inefficient mining, illegal trading of high-value minerals, and massive revenue loss to the government (Fayemi, 2015) [13] and has given birth to banditry, kidnapping and all forms of terrorism be devilling some of the states in the North West and North East Nigeria.

Kebbi State is one of the states that is blessed with solid minerals. The State lies between latitudes 10° and 13° N and longitudes 3° and 6° E on the globe. It is found in the North-western Geopolitical Zone in Nigeria and shares its borders with Sokoto State to the north, Niger State to the south, and Zamfara State to the east. It has a total land mass of 36,800 km^2 (Yahaya *et al*., 2022) [30]. The State is blessed with solid minerals that have been lying untapped.

With these solid mineral deposits, Kebbi State would have been able to stand on its own economically. According to the report by Atulegwu the following minerals deposits are found in Kebbi State: gold, found in Yauri; copper in Gwandu, Zuru and Jega; Manganese in Gwandu, Bagudo and Zuru; and aluminium in Jega, Zuru, Yauri, and Birnin Kebbi. Other deposits are; iron ore, feldspar, quartz, clay, and magnesite (Danjumma, *et al*., 2019) [10] and probably many more that are yet to be identified.

Many researchers have made attempts to explore the solid minerals available in Kebbi State: Danbatta, Abubakar, & Ibrahim, (2009) [9] explore the potential of gold deposits in the Anka Schist belt, Bonde, Lawali, & Salako, (2019) [5] mapped out the potential areas where mineral deposits could be found in Southern Kebbi, Augie *et al*., (2021) [3] explore the gold mineralization potential in the southern part of Kebbi State, and Augie, *et al*., (2022) [2] explore the possibility of tracing manganese ore in Western Kebbi. Most of the survey carried out has centred more on gold deposits neglecting the other available solid minerals in the State. More need to be done to explore other solid minerals, their locations and the viability of mining and processing them.

1.1. Factors that determine the viability of mining a solid mineral deposit

It is one thing to identify where these mineral deposits are found and another thing to be able to mine and process them profitably. Several factors determine whether it will be economical or not to mine a solid mineral deposit in a given location. These factors include the price value of the mineral, the accessibility of the location, the quantity and quality of the mineral deposit, the cost of mining, and the technical knowledge on how to reclaim them (Council, 2002) [8]. These are the basic information that the Kebbi state government must obtain and document to be able to attract investors in the solid minerals sub-sector.

The quantity and quality of these deposits need to be evaluated and documented. For information on the quality of a deposit, a chemical analysis must be carried out to know the assay of the mineral content in the ore deposit and if there are other harmful impurities in the deposit, they must be as low as possible, otherwise, their presence could render the mining of a deposit unprofitable; e.g the presence of sulphur in an iron ore deposit. The quantity of the mineral deposit is also very important because this will determine how many years it will take to exhaust the deposit.

The steps for reclaiming solid mineral deposits starts from clearing the sites, setting up the machineries, drilling or blasting using explosives and transporting the mineral to the processing site. In this paper, however, the focus is on the beneficiation/dressing of iron ore. The reason for this choice is that Nigeria has invested so much to build Ajaokuta Steel Complex in Kogi State, which is yet to be functional, and the recent commitment of the past Muhamadu Buhari-led Administration to complete the Ajaokuta Steel Complex and make it functional. Also, the Federal Government targets to raise the GDP in the solid mineral sector to 5.0% by the year 2025. With this development, iron ore deposits scattered in many States including Kebbi state could be mined and processed for the Iron and Steel Complex. With the excessive demand for iron and steel in Nigeria for various applications including building construction, automobile spare parts, and other structural applications, many unemployed youth roaming the streets will be gainfully employed across the States including Kebbi.

2. Types of Iron Ore Deposits

Iron ore is a naturally occurring mineral deposit that serves as a major source of iron. It contains the valuable part, which is the mineral consisting of iron combined with other constituent elements in definite proportions; and the unwanted part referred to as gangue particles. It is used to produce pig iron in the blast furnace and subsequently; various grades of steel. There are close to 300 different types of ore deposits containing iron, but the four most common of them will be considered in this paper.

Table 1: Types of Iron Ore Deposits (Michaud, 2016) [21]

S/N	Mineral	Chemical formula	% iron
1	Hematite	Fe_2O_3	70.0
2	Limonite	$2Fe_2O_3.3H_2O$	59.8
3	Magnetite	Fe_3O_4	72.4
4	Siderite	$FeCO_3$	48.2

From Table 1, it is shown that magnetite has the highest amount of iron in the mineral well siderite has the lowest. However, the amount of sulphur in an iron ore deposit could undermine the viability of mining them due to the negative effect of this element in cast irons and the high cost of removing it during iron making process. This means that it may be more profitable to mine an ore deposit containing 35% magnetite and 0.5%S as impurity rather than mining an iron ore deposit containing 45% magnetite and 2.0%S as impurity. Fig (a)-(d) are the macro-view of four different types of iron ore (Michaud, 2016) [21].

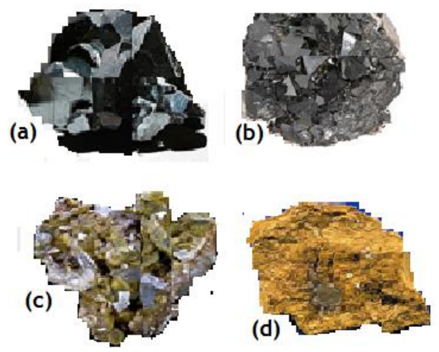

Fig 1: The macro-view of iron ore deposits: (a) Hematite, (b) Magnetite, (c) Limonite, (d) Siderite

3. Beneficiation of iron ore

The beneficiation process, also called ore dressing or mineral processing, includes crushing, grinding, and final separation of the minerals from the gangue particles. When this process is completed the concentrate obtained usually contains a higher assay of the mineral and a lower amount of gangue particles suitable for the reduction process in the blast furnace.

3.1. Crushing

Iron ore deposits are usually found in rocky areas that could be OF igneous, sedimentary or metamorphic origins. Because of the nature of the environment, the ore is usually obtained by blasting such areas using explosives to obtain very big lumps whose sizes could be up to 40 inches that need to be crushed using a crushing machine to reduce them to manageable sizes for further processing (Walker, 2001) [28].

3.2 Grinding and drying

This is carried out to further reduce the particle sizes. The grinding machines used for this purpose are usually either ball or rod mills. The primary objective of grinding is to reduce the ore to its liberation size. Liberation, here, refers to the actual separation of the minerals (e,g Fe_2O_3) from the gangue particles. Different ores could have different liberation sizes, which are usually well documented.

3.3 Separation Process

Iron ore deposits could consist of large amounts of unwanted (gangue) materials, which render them unsuitable for use in the blast furnace. There are different separation techniques used to eliminate most of the gangue particles from an ore to avoid wasting energy carrying gangue particles through long distances or into the furnace. These separation techniques include gravity separation, magnetic separation, froth floatation and leaching.

- **Gravity Separation:** This is an industrial separation technique that employs the differences in densities to separate two different components. In this method, the mineral, which is usually denser, sinks to the bottom while the unwanted particles, usually water-soluble or lighter gangue particles, float and find their way out. This process is mostly used to dress hematite minerals though it could be used for other minerals.
- **Magnetic Separation:** This process is used to separate magnetite mineral (Fe_3O_4) which is magnetic. The process employs the use of strong magnets to attract the magnetite mineral while the gangue particles are disposed off far away. In this process, the ore fines containing the mineral are transported on a conveyor belt to a place where there is a magnetic drum rotating at the exit point. The magnetic drum attracts the magnetite ore while the gangue particles are collected separately as shown in Figure 21).

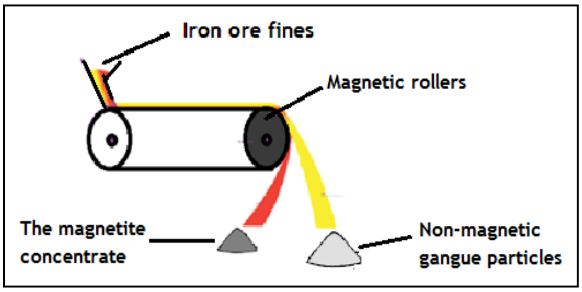

Fig 2: Magnetic separation process (BYJU, 2021) [6]

- **Froth Floatation:** This method is usually employed for the beneficiation of low-grade ores (Srivani & Noothana, 2019) [27]. The differences in wettabilities of the different components in the ore is the basis for the froth flotation process. The ore or gangue particles could easily be wettable by water (hydrophilic) or may be water-repellent (hydrophobic). This method is a versatile process for physically separating particles in a mineral/water slurry based on the differences in air bubbles' propensity to preferentially attach to specific mineral surfaces. The particles with associated air bubbles are transported to the surface and eliminated, while those that are entirely wet remain in the liquid phase. Since chemical treatments can be used to selectively change mineral surfaces to give them the qualities needed for separation, froth flotation can be applied to a wide range of mineral separations (Kawatra, 1995) [17].
- **Leaching:** This process is associated with the extraction of metals that are found in rocky areas. Here, a solvent is poured on the surface containing the required metal; the solvent dissolves the mineral, which is later recovered. The branch of extractive metallurgy that deals with the recovery of metals using this process is referred to as hydrometallurgy.

4. Agglomeration Processes

The ore fines collected during the grinding and separation processes are usually not suitable for the blast furnace hence, the need for agglomeration processes that transform the ore fines into bigger lumps such as pellets, briquettes or sinters (Bhattacharyya, *et al*., 2019) [4].

4.1. Drying, Calcination and Roasting

Drying is the first step where physically bonded water is completely removed from the ore concentrate. Calcination is carried out to drive away chemically bonded water, also called water of crystallization, as well as other volatiles that may be present in the ore fines. Roasting, on the other hand, is the process whereby an ore concentrate is heated in the presence of oxygen to convert iron sulphide (FeS) to iron oxide (FeO). This is done to reduce the sulphur (S) content in the form of sulphur dioxide (SO_2) as shown in equation (1). This process could also be used to convert hematite ore to magnetite to employ the magnetic separation technique.

$$2FeS+3O_2 = > 2FeO+2SO_2 \quad (1)$$

4.2 Sintering

Sintering is a thermal agglomeration technique for iron ore fines, recycled iron-making products, fluxes, slag-forming agents, and solid fuels (coke) (Fernández *et al*., 2017b) [15]. It is the most economical and widely acceptable agglomeration process for preparing ore fines into lumps for the blast furnace (Lu & Ishiyama, 2015, 2016) [19-20]. The goal of the sintering process is to create a product with the right thermal, mechanical, physical, and chemical properties to feed into the blast furnace. In the iron and steel-making business, the process has been extensively investigated and analyzed to determine the ideal conditions for obtaining the best sinter quality. Sintering temperature ranges between 1300 to 1480^{0}C to facilitate incipient fusion and formation of a spongy solid called sinter (Fernández, *et al*., 2017a) [14]. The mixture of ore fines and the other constituents mentioned above passes through the sintering kiln (Lu & Ishiyama, 2015) [19]. The process starts with charging and mixing the constituents in a drum then passing the mixture through a hopper onto a conveyor belt being heated at the bottom to facilitate incipient fusion. The sinters are collected on a screen to select suitable sizes for the blast furnace. The macro-view of a sinter is shown in Fig 3.

Fig 3: Macro-view of an iron ore sinter (Nicol *et al*., 2019) [23]

4.3 Pelletizing

This is another method of agglomeration where iron ore concentrate is mixed with a binder such as bentonite, inorganic salts and water and rolled into pellets using a rotating drum. Pellet binders must meet several practical characteristics, including being easily disseminated throughout the pellet, successfully controlling water movement within the pellet, and contributing to inter-particle bonding (Srb & Ruzickova, 1988) [26]. By effectively managing the growth of pellets as they are pelletized, meeting these conditions results in the formation of hard pellets. The pellets are then fired on a kiln to give them the required physical, chemical and metallurgical properties suitable for use in the blast furnace (de Moraes, *et al*., 2018; Kawatra & Claremboux, 2021) [11, 18]. Pellets are characterized by high-grade mineral content, low gangue particles and better metallurgical properties than sinters, which are characterized by high energy consumption and high emissions of flue gases (Zhang *et al*., 2021) [31]. A macro view of pellets is shown in Fig 4.

Fig 4: Iron ore Pellets (Cooke, 2020) [7].

4.4. Briquetting

Briquettes are made by squeezing tiny particles from coking coal and pellet feed iron ore into a cylindrical die before heating them (Narita, *et al*., 2015) [22]. Traditional processes such as sintering and pelletizing have limitations in terms of particle size of ore fines that could be used for the processes; hence placing the briquetting process at an advantage. Furthermore, sintering, pelletizing are capital-intensive with greater operational expenses (Bhattacharyya *et al*., 2019) [4]. A macro-view of a briquette is shown in Plate 4.

Fig 5: Macro view of a briquette (Bhattacharyya *et al*., 2019) [4]

5. Extraction of Metals

Apart from gold, most metals are found in their combined form such as oxides, sulphides, carbonate, etc. For this reason, it is always necessary to develop a means of recovering the metals in their free states. The methods usually employed are, pyrometallurgical (involving the use of heat), hydrometallurgical (use of water or other fluids) and electrometallurgical (electrolytic) process (Roundhill, 2001) [25].

Extractions of metals from their ores are usually reduction processes except for a few minerals such as gold which is usually found in its uncombined form due to its nobility. The three main types of reduction used for extraction of metals include i) electrolytic reduction, which is used for very reactive metals such as sodium and aluminium; ii) chemical reduction which is used for moderately reactive metals such as iron, zinc, and tin; and thermal reduction used for the least reactive metals such as silver. For this paper, the focus has been centred on the extraction of iron using the chemical reduction process.

5.1. Iron making process

Chemical reduction is the method used for smelting of iron in the blast furnace. It employs the use of strong reducing agents to free the iron from its oxide. The reducing gas used in this process is usually carbon monoxide. Table (1) below shows the raw materials required in the blast furnace and the role each of them plays during the smelting process.

Table 2: Raw materials used during iron making and their functions

S/No	Raw Material	Function in the blast furnace
1	Iron-bearing materials (sinters, pellets or briquettes)	This serves as the source of iron in the blast furnace. It is usually the final product of the beneficiation process e.g. Sinter which is most commonly used.
2	Coke (a form of carbon)	Coke plays two major roles in the blast furnace: it burns to provide the heat required during the smelting process and also serves as the source of reducing agent in the form of carbon monoxide or carbon.
3	Air blast	This provides the oxygen needed to support the combustion of coke.
4	Lime stone/lime ($CaCO_3$/CaO)	It is used as the flux (slag-forming agent) – its role is to combine with the unwanted part associated with the mineral to form slag which is usually less dense and floats on the molten metal.

The end-product of the blast furnace process is the liquid metal called 'pig iron' which, could contain as high as 6.67%C and other elements such as Si, Mn, P, S, etc; in smaller quantities. Three things happen after tapping the molten pig iron from the blast furnace: i) it could be transported to a steel-making plant for its conversion to steel; ii) it could be treated in a ladle by addition of other alloying elements before pouring the liquid metal into a mould cavity to form a finished products, or iii) it could be cast into ingots for future processing such as forging, rolling, extrusion etc.

6. Conclusion

Despite the efforts of the few researchers who have tried to identify different solid mineral deposits available in Kebbi State, Nigeria, the available data on these minerals are not satisfactorily available to preempt major mining activities. Kebbi State Government, as a matter of urgency, should make proper exploration and documentation of the data on the various solid minerals available, and provide the necessary infrastructures needed to attract investors to come and develop the sector for the public good. The locals need to be trained on the technical knowledge on how to mine, dress and process some of these minerals into finished or semi-finished products to facilitate their extraction. The solid minerals, if properly harnessed, will boost the Internally Generate Revenue of Kebbi State, provide employment opportunities to the teeming unemployed youths, improve the infrastructural development, raise the standard of living of the people and possibly checkmate the illegal mining activities that may culminate in banditry, kidnapping, and other acts of terrorism as being experienced in some parts of the north-western States today.

7. References

1. Atulegwu D. List of Natural Mineral Resources Found in Kebbi State; c2021. Retrieved from https://nigerianinfopedia.com.ng/mineral-resources-found-in-kebbi-state/?unapproved=40238&moderation-hash=390ef13cb01cc457a9dcb56d6bf459df#comment-40238, 27/07/2021.
2. Augie A, Bawa Y, Saleh A, Magawata U, Garba N. Tracing the Structures Associated with Manganese over the Western part of Kebbi using Aeromagnetic Data. Paper presented at the Science Forum. Journal of Pure and Applied Sciences; c2022.
3. Augie AI, Adamu A, Salako K, Alkali A, Narimi A, Yahaya M, *et al*. Assessment for Gold Mineralisation Potential over Anka Schist Belts Nw Nigeria, Using Aeromagnetic Data. FUDMA Journal of Sciences. 2021;5(4):235-242.
4. Bhattacharyya A, Biswas C, Mitra M, Dey R. Cold briquetting of iron ore fines for DRI production: challenges, possibilities and solutions, Researchgate.net; c2019.
5. Bonde D, Lawali S, Salak K. Structural Mapping of Solid Mineral Potential Zones over Southern Part of Kebbi State Northwestern Nigeria. Journal of Scientific and Engineering Research. 2019;6(7):229-240.
6. BYJU. Concentration of Ore BYJU'S Classes. Retrieved from; https://byjus.com/chemistry/concentration-of-the-ore/ 27/07/2021.
7. Cooke R. Iron ore 'one of the highlights' of NL. Economy amid catastrophic pandemic, CBC; c2020.
8. Council NR. Evolutionary and revolutionary technologies for mining: National Academies Press; c2002.
9. Danbatta U, Abubakar Y, Ibrahim A. Geochemistry of gold deposits in Anka Schist Belt, Northwestern, Nigeria. Nigerian Journal of Chemical Research. 2009;14:19-29.
10. Danjumma SG, Senchi DB, Sale L, Mohammed A, Tudu AMB. Identification of Mineral Deposits in Garin Awwal Mining Site, Kebbi State, North-Western Nigeria. Environment; 2019:6(6).
11. De Moraes SL, De Lima JRB, Ribeiro TR. Iron ore pelletizing process: An Overview. Iron Ores and Iron Oxide Minerals; 2018:41-59.
12. Ewepu G. FG targets 5% growth as a contribution to GDP for solid minerals sector by; c2025, Vanguard Newspaper. Retrieved from https://www.vanguardngr.com/2021/07/fg-targets-5-growth-as-contribution-to-gdp-for-solid-minerals-sector-by-2025/ 27/07/2021.
13. Fayemi K. The Role of Solid Minerals In Nigeria's Economy As We Diversify From Crude Oil. Nigerian Television Authority Broadcast, Abuja; c2015.
14. Fernández-González D, Ruiz-Bustinza I, Mochón J, González-Gasca C, Verdeja LF. Iron ore sintering: Process. Mineral Processing and Extractive Metallurgy Review. 2017a;38(4):215-227.
15. Fernández-González D, Ruiz-Bustinza I, Mochón J, González-Gasca C, Verdeja LF. Iron ore sintering: Raw materials and granulation. Mineral Processing and Extractive Metallurgy Review. 2017b;38(1):36-46.
16. Ighodalo B. Solid Minerals: Harnessing Nigeria's Viable Alternative resource To Crude Oil. Retrieved from, https://www.banwo-ighodalo.com/assets/grey-matter/bfd7631091ed3b8c29fa9a1d949dd4a5.pdf 21/07/2021.
17. Kawatra K. Froth Flotation–Fundamental Principles Flotation System. Minerals Engineering; 1995:1-30.
18. Kawatra S, Claremboux V. Iron Ore Pelletization: Part I. Fundamentals. Mineral Processing and Extractive Metallurgy Review; 2021:1-16.
19. Lu L, Ishiyama O. Iron ore sintering Iron Ore, Elsevier; 2015:395-433.
20. Lu L, Ishiyama O. Recent advances in iron ore sintering. Mineral Processing and Extractive Metallurgy. 2016;125(3):132-139.
21. Michaud D. Different Types of Iron Ore 911 Metallurgist; c2016 ed., Retrieved on 22/07/2021.
22. Narita CB, Mourao M, Takano C. Development of composite briquettes of iron ore and coal hardened by heat treatment. Ironmaking & Steelmaking. 2015;42(7):548-552.
23. Nicol S, Chen JQW, Mao X, Jak E, Hayes PC. Measurement of process conditions present in Pilot scale iron ore sintering. Minerals. 2019;9(6):374.
24. OSGF. National Policy On Solid Minerals And Metals. Office of the Secretary to the Federal Government of Nigeria. Retrieved from https://www.osgf.gov.ng/resources/policies/solid-minerals 27/07/2021
25. Roundhill DM. Extraction of metals from soils and waters: Springer Science & Business Media; c2001.
26. Srb J, Ruzickova Z. Pelletization of fines; c1988.
27. Srivani P, Noothana P. Beneficiation of Manganese Ore Using Froth Flotation Technique. Materials Today:

Proceedings. 2019;18:2279-2287.
28. Walker RD. Iron Processing Britanica; c2001.
29. Xinhai. Mineral Processing EPC. Iron Beneficiation Plant. Retrieved on 5th July; c2021.
30. Yahaya T, Ologe O, Yaro C, Abdullahi L, Abubakar H, Gazal A, & Abubakar J. Quality and Safety Assessment of Water Samples Collected from Wells in Four Emirate Zones of Kebbi State, Nigeria. Iranian (Iranica) Journal of Energy & Environment. 2022;13(1):79-86.
31. Zhang Y, Wu X, Niu H, Zhao M, Qing G, Zhao Z, *et al*. Study on Sinter Iron Ores and Titanium Ores Used in Pelletizing. Paper presented at the Characterization of Minerals, Metals, and Materials; c2021.