10.51975/24390207.som
Journal of the Nigerian Society of Chemical Engineers, 39(2), 2024

COMPARATIVE ANALYSIS OF IMPORTED AND LOCALLY SOURCED GYPSUM FOR CEMENT PRODUCTION

Justus T. OMOYAKHI[1], *Kenneth K. ADAMA[1], Ubani O. AMUNE[1], Francis A. OLUWADAYO[1], Shegun K. OTOIKHIAN[1], Emmanuel O. ALUYOR[1]

[1]*Department of Chemical Engineering, Edo State University Uzairue, Edo State, Nigeria*

Correspondence: *omojust1988@gmail.com[1], ubani.amune@edouniversity.edu.ng[1], adama.kenneth@edouniversity.edu.ng[1], and otoikhian.kevin@edouniversity.edu.ng[1] +234(0)8137147909*

ABSTRACT

The availability and use of local gypsum for cement production have become imperative in the Nigerian cement industry. In this research, local and imported gypsum were analyzed comparatively using different characterization techniques: X-ray fluorescence (XRF), Fourier Transform Infrared Spectroscopy (FTIR) and Brunauer-Emmett-Teller (BET). Dry and wet-beneficiation techniques were employed on different samples identified as Spain-A, Warake-B, Afuze-C, Avilele-D, Warake-B1, Afuze-C1 and Aviele-D1, respectively. The initial samples were crushed and sieved to 2 mm, and 500 g of each sample was heated to 45 °C for 24 hrs as dry-beneficiated. Three hundred grams (300 g) of each sample was then soaked for 24 hrs as wet-beneficiated. The dry and wet-beneficiated samples were further heated to 120 °C for 30 mins, and 10 g of each sample was ground and sieved to 45 µm for analysis. The XRF results showed improvement in the active component and SO_3 purity of Warake gypsum, ranging from 72.26% and 86.93% to 75.45% and 91.59%, respectively, using wet-beneficiation. The various local gypsum samples had higher purity levels than Spain gypsum after wet-beneficiation. The FTIR analysis revealed the presence of different functional groups for all samples consisting of –COOH, −OR, $CO-NH_2$, −C≡N, −OH, C=O, C−I, Br, F, C=C and −C≡C−, which are involved in ionic interaction with clinker mineral. BET analysis revealed improvement in surface area and pore size of 204.515 m^2/g and 1.853 nm to 265.156 m^2/g and 2.108 nm for Aviele wet-beneficiated gypsum. Investment cost analysis for local gypsum production revealed a profit of ₦ 25,104.20 when the cost of producing local gypsum is compared to the cost of importing Spain gypsum per ton, establishing the quality and potentials of different local gypsum for cement production in Nigeria.

Keywords: *Gypsum; Beneficiation; Characterization; Purity composition; Cost*

1 INTRODUCTION

Gypsum is a naturally occurring mineral with the chemical formula ($CaSO_4.2H_2O$) known as calcium sulfate dihydrate. (Al-Ridha *et al.,* 2020; Layr and Hartlieb, 2019). As a set-retarder, gypsum is widely employed in the manufacture of cement. When added to cement, it prolongs the process of hydration and delays the setting time of the cement (Abdul-Wahab *et al*., 2021). By forming ettringite, gypsum addition slows down the tri-calcium aluminate $3CaO.Al._3/C_3$ A's rapid exothermic reaction (Muhammad *et al.,* 2021). In order to create cement with a high compressive strength and minimal concrete expansion, gypsum is added to the clinker (Xiaodi *et al.,* 2022). Gypsum can take a variety of forms when heated, such as Gypsum, $CaSO_4.2H_2O$, hemihydrate $CaSO_4.0.5H_2O$ (mortar), and anhydrates $CaSO_4$ (Adams *et al.,* 2021; Gaharwar *et al.,* 2016; Muhammad *et al*., 2021).

The global gypsum production in 2016 was estimated at 252 million tonnes, valued at $1.49 billion, with 33.3 % and 60.9 % being consumed in the plasterboard and cement industries, respectively (Uriah, 2016). Gypsum output, according to Uriah (2016), is expected to increase at a compound annual growth rate of 9.9% and will reach about $3.8 billion by 2026. For instance, there are more than a billion tons of gypsum deposits in Nigeria, which are dispersed across a number of the nation's states, including Taraba, Sokoto, Borno, Bauchi, Adamawa, Edo, Yobe, Gombe, Ogun, Ebonyi, and Cross River State (Dogara & Aloa, 2017; Muhammad et al., 2021). Despite these substantial resources, Nigeria imported $56 million worth of gypsum over the past three years (Adams et al., 2021). An estimated 4,000,000 tons of gypsum are located in several local government areas of Edo State (Uriah, 2016).

Gypsum is widely used in cement production to control cement settings and to provide cement with less drying shrinkage and non-excessive expansion in concrete. It is always added to clinker at an optimal level during grinding (Dafni *et al.,* 2019; Mohammad *et al.,* 2022). The purity of gypsum for cement production is required to be between 85-90 %, and where the purity of the gypsum produced locally does not meet this requirement, beneficiation is expected to be carried out to upgrade its purity (Uriah, 2016).

Very few research articles have attempted to analyze the quality of locally sourced Gypsum in Nigeria and its effect on cement production. For instance, Adams *et al.* (2021) worked on the facile purification of locally mined gypsum and its use for preparing nano-hemihydrates using $CaCl_2$-based solvent and achieved high gypsum purity (94.05%). Their work failed to carry out physical beneficiation and non-chemical-based investigation as a cheaper means of solvent beneficiation. Also, Muhammad *et al*. (2021) investigated the effect of locally sourced Nigerian Gypsum (Warake) on the strength and microstructure of Portland cement mortar. They obtained a similar range for foreign and local gypsum content for optimal Portland cement (5 to 6%). However, an intricate analysis of the locally sourced and foreign gypsum prior to its use for ordinary Portland cement, amongst other uses, was not covered in their report. Hence, this study characterized Local Gypsum and compared it to gypsum imported from Spain in order to understand its properties and suitability for cement production while considering its cost of production. The purity, composition, and physiochemical properties of the local and imported gypsum samples were compared along with the industrial cost of importation and local production. Beneficiation methodology was used to fully explore the suitability of warake gypsum over popularly imported (Spain) gypsum for cement production.

2 MATERIALS AND METHODS

2.1 Materials

The materials used in the study include gypsum samples from Warake (randomly selected from Alagbon, Iyekhara, and Akagbe villages), Afuze (Oke, Eme, and Afuji villages), and Aviele in Owan East and Etsako West Local government areas of Edo State, Nigeria. The Warake gypsum was located approximately between Latitudes 6° 58' 54"N and 6° 56' 27"N and between Longitude 6° 13' 25"E and 6°11' 25" E. Avielle gypsum was also located at Latitude 6° 56’ 51" N and Longitude 5° 59’ 38.04" E, while Avielle gypsum was located at Latitude: 7° 0’ 51.57" N and Longitude: 6° 16’ 42.4884" E. Random depths of 1.5m, 4m, and 7m were used to retrieve samples (2, 3, and 4 pieces) at each of these locations. Spain gypsum was obtained from Spain through a gypsum vendor. Table 1 and Plate 1 present different materials used in the study.

Table 1: List of Materials Used for the Experiment

Material	Source	Colour comments
Spain gypsum	Spain	Light brown
Warake gypsum	Warake (Edo state – Nigeria)	Dark brown

2.2 Methods

2.2.1 Preparation of the Spain imported gypsum

The Spain-imported Gypsum (SIG) was prepared using the ASTM (C471) method. Three hundred grams (300 g) of the SIG was crushed with a laboratory crusher and dried in an oven at 45°C for 24 hrs to remove the moisture content. The SIG was subjected to heat treatment at 120°C for 30 mins. After that, the samples were pulverized into powder using an ASTM 45 µm mesh-sized sieve and compacted on a ring in a manual press machine. Ten grams (10 g) of prepared sample was then collected and analyzed using XRF, XRD, FTIR, and BET techniques.

Plate 1: Samples of the Warake (left) and Spain-imported Gypsum (SIG Right) used for the study

2.2.2 Preparation of the Local Gypsum

The Warake gypsum sample was equally prepared using the ASTM (C471) method. Five hundred grams (500 g) of gypsum sample from Warake, Afuze, and Avielle (Edo State) Nigeria was crushed into smaller sizes and dried in an oven at 45°C for 24 hrs to remove the moisture content. The gypsum was then homogenized, and 300g was weighed using a laboratory scale and beneficiated using the dry and wet methods.

2.2.3 Beneficiation of the Local Gypsum

The physical methods for dry and wet-beneficiation of Gypsum by Adams et al. (2021), Gunnar and Kristine (2020), and James et al. (2008) were used. The Dry-beneficiation method involved crushing the sample material into the desired size and sieving with a mesh of 2-micrometer size. In contrast, in the wet-beneficiation method, the samples were soaked with ordinary tap water at a room temperature of 27 ± 2 °C for 24 hours, thoroughly washed and heated to 45 °C for 24 hours, and then sieved using 2-mm mesh to separate smaller particles from larger particles and impurities. The dry-beneficiated samples of the Warake, Afuze, and Avielle samples were labeled as B, C, and D, respectively while the wet-beneficiated samples were equally labeled as B1, C1, and D1, respectively.

2.2.4 Preparation of hemihydrate

The method adopted for the preparation of hemihydrate was that reported by Adams *et al.* (2021). The four gypsum samples were further heated in an oven to 120 °C for 30 minutes to eliminate some of the water of crystallization for hemihydrate determination. After this, the samples were pulverized into powder using an ASTM 45 µm mesh-sized sieve and compacted on a ring in a manual press machine, just as done for the SIG. Ten grams (10 g) of prepared sample was then collected and analyzed using XRF, XRD, FTIR, and BET techniques.

2.2.5 Characterization using XRF, XRD, FTIR and BET

The elemental composition of the gypsum samples was determined using X-ray fluorescence (XRF). A Switzerland Thermo Scientific ARL 9900 XRF equipment was utilized to determine the elemental composition of the different samples and the percentage of CaO, SO_3, and impurities in the different samples. A Rigaku Mini-flex 600 XRD equipment from Tokyo, Japan, was employed for structural analysis of the gypsum samples. The equipment parameter consisted of CuK radiation operated at a wavelength of 1.5406 λ, 40 kV, 30 mA, and a scanning speed of 8 °/min. The 2Θ angle of measurement was in the range of 5° to 70°. Fourier Transform Infrared Spectrometer (FTIR) measurements were performed using an Agilent Cary 630 instrument, Agilent Technologies Inc., USA, to ascertain the phase composition and functional groups. The equipment was operated on 100-240 VAC with a frequency of 50-60 Hz. Brunauer-Emmett-Teller (BET) analysis was used to determine the specific surface area, pore volume, and pore size distribution of the samples. This was accomplished using a Nova 4200e U.S.A BET device. The surface areas were computed by counting the number of N_2 molecules adsorbed at monolayer coverage. Prior to BET analysis, the samples were degassed at 300 °C for 3 hrs to eliminate any physically adsorbed water molecules.

2.2.6 Density determination

ASTM (D792) methodology was employed to determine the density of the samples. The gypsum powder samples sieved with 45 µm ASTM-graded mesh were placed in a weighted density bottle, compressed, and reweighed in a weighing balance. The density of each sample was then estimated using the volume of the density bottle (25 ml) as in Equation 1.0 (Bouzit *et al.,* 2019)

$$\text{Density} = \frac{m_2 - m_1}{v_2 - v_1} \quad (1)$$

Where m_1 and m_2 are the initial and final weight of the samples on the bottle, and v_1 and v_2 are the initial and final volume of the bottle, respectively.

2.2.7 Moisture Content Determination

The moisture content of each sample was determined using the ASTM (D2216-19) method. On a weight balance, the weight of an empty laboratory container was recorded, and 500 g of each sample was weighed into the container, with the total weight recorded. The weighted mass was placed in a 45°C oven for 24 hrs. The new weight of the samples was recorded after 24 hrs, deducted from the initial weight, and the findings were determined using Equation 2.0 (Randazzo *et al.,* 2016).

$$\text{Moisture content} = \frac{w_1 - w_2}{w_1} \times 100\% \qquad (2)$$

Where w_1 and w_2 are the initial and final weight of gypsum after heating, respectively.

3 RESULTS AND DISCUSSION

3.1 Physical Properties of Investigated Gypsum Samples

The results of the investigations conducted on the different samples in terms of their physical properties, which include moisture content, density, surface area, pore size and pore volume, are presented in Table 2.

Table 2: Physical Properties of Different Gypsum Samples

Sample		Moisture content (%)	Density (g/ml)	Surface area (m^2/g)	Pore size (nm)	Pore volume (cm^3/g)
SIG	A	1.2	2.86	257.272	2.123	0.143
Warake	B	0	2.98	289.924	2.144	0.180
Afuze	C	0	2.78	270.108	2.122	0.149
Aviele	D	0	2.69	204.515	1.853	0.135
Warake	B1	2.8	2.82	316.747	2.153	0.162
Afuze	C1	2.8	2.30	292.598	2.101	0.179
Aviele	D1	2.8	2.34	265.156	2.108	0.130

3.1.1 Moisture content analysis

Table 2 above shows the results of the moisture content of dry- and wet-beneficiated investigated gypsum samples. Moisture content measurement reveals the water binding ability and hydration behaviour of gypsum samples for consistency testing and performance assessment. It is an important physical characteristic that reveals the amount of water in gypsum and its relationship with the environment. No moisture content was observed in all local dry-beneficiated samples, as seen in Table 2, while a variation in moisture content between the SIG and the wet-beneficiated gypsum. The wet-beneficiated samples, because of their beneficiation process, have more water content, i.e. 2.8 %, while the SIG sample is 1.2 %. The variations in Table 2 can be attributed to the nature of occurrence in different regions and exposure to water, which might have caused changes in moisture content (Gunnar and Kristine, 2020). Several studies by Ahmad *et al*. (2021), Abdul-Wahab *et al.* (2021) and Mohamad *et al.* (2022) revealed that moisture levels should not be more than 2–3 % to avoid problems like clogging of the grinding mill or agglomeration of mineral particles. Zmemla *et al.* (2016) also noted moisture content ranging from 1–2 % for natural gypsum.

3.1.2 Density analysis

Gypsum has a relatively low weight per unit volume due to the presence of impurities (Cordon *et al.,* 2021). Table 2 shows the density values of the investigated SIG and local gypsums. The diverse percentages of crusts and impurities present in the various samples may be responsible for this variance. However, though wet-beneficiation was shown to decrease the density of the local gypsum samples by reducing the impurities present (Mohamad *et al.* 2022), the resulting densities were still in accordance with gypsum density values reported by different authors (Onat *et al.,* 2018; Mohammad *et al.,* 2022; Mohamad *et al*., 2022). As shown in Table 2, the total sample density ranges between 2.30 and 2.98 g/ml.

3.1.3 BET analysis

3.1.3.1 Surface area, pore size and pore volume of dry-beneficiated Gypsum Samples

The pore sizes of gypsum have a significant impact on the estimation of hydration and hydraulic characteristics. Increased dissolution rates, higher adsorption capacity, and free energy available for bonding are all benefits of a solid with a high surface area (Adamas *et al.,* 2021; Ghumman *et al.,* 2022). The surface area, pore size, and pore volume of dry-beneficiated gypsum samples (SIG and local) are shown in Table 2. The BET technique was used to analyze the weak forces of attraction using gas adsorption on particulate materials (Cordon *et al.,* 2021). The dry-beneficiated SIG-A, Warake-B and Afuze-C were all mesoporous materials. In contrast, the dry-beneficiated Aviele gypsum sample D showed a microporous property showing close matching pore diameters as presented in Table 2. This observation is consistent with the result reported by Amenaghawon *et al.* (2021). Gypsum's reactivity and hydraulic characteristics in the manufacture of cement are impacted by higher surface area and pore size (Cordon *et al.,* 2021; Gunnar and Kristine, 2020).

3.1.3.2 Surface area, pore size and pore volume of wet-beneficiated Gypsum

The surface area, pore size, and pore volume of the wet-beneficiated local gypsum samples are displayed in Table 2. The wet-beneficiated Warake gypsum sample B1 improved in surface area from 289.924 m^2/g to 316.747 m^2/g with an increment of 26.823 m^2/g after wet-beneficiation. The pore size increases while the pore volume decreases from 0.180 cm^3/g to 0.162 cm^3/g. The surface area of Afuze wet-beneficiated local gypsum sample C1 increases from 270.108 m^2/g dry-beneficiated to 292.598 m^2/g. This shows an improvement in the surface area due to wet-beneficiation with 22.49 m^2/g increment. The pore size decreases after wet-beneficiation from 2.122 to 2.101 nm while the pore volume increases, which also indicates the effect of its hardness. Wet-beneficiated Aviele gypsum sample D1 also shows improvement in the surface area from 204.515 to 265.156 m^2/g. The microporous nature of the dry-beneficiated Aviele local gypsum sample (1.853 nm) becomes mesoporous (2.108 nm) after wet-beneficiation with a decrease in the pore volume. High pore size and surface area are needed for effective reaction, and this reaction is within the crevices of the material.

3.2.1 XRF analysis

3.2.1.1 XRF Analysis Result of Dry-Beneficiated Gypsum samples

The elemental compositions and active components of dry-beneficiated SIG and Local gypsum samples are shown in Tables 3 and 4, respectively, while Table 5 compares the elemental compositions of gypsum obtained from literature with the present study. These compositions show the requirement in terms of gypsum purity.

Table 3: Elemental Compositions of Dry-Beneficiated SIG and Local Gypsum

Elemental Compositions	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)	Cl (%)
SIG A	2.57	0.74	0.72	31.72	0.81	0.11	0.09	41.83	0.003
Warake B	3.35	1.05	1.05	31.81	1.41	0.11	0.03	40.45	0.008
Afuze C	1.72	0.72	1.36	31.60	0.93	0.07	0.02	42.93	0.002
Aviele D	1.61	0.66	1.11	31.58	0.88	0.07	0.00	43.44	0.000

Generally, gypsum contains oxides of silicon, aluminium, iron, calcium, magnesium, sulphur, potassium, chlorine, and sodium, as well as trace amounts of nickel, barium, phosphorus, titanium, and a few others in varying quantities, depending on their sources and pretreatment methods. The highly active component (CaO) and SO_3 indicate purity and efficiency in cement setting time (Muhammad *et al*., 2021). The high presence of impurities can degrade the quality of cement. The active component levels in the gypsum samples from SIG and Local conform to previously studied local and foreign samples and are even higher in some others (England sample). Overall, the composition of active components in the Local gypsum samples is favourable, making them appropriate for cement manufacture. Table 4 presents the active components of the dry-beneficiated SIG and Local gypsum sources and the requirement in terms of gypsum purity.

Table 4: Active Components of Dry-Beneficiated SIG and Local Gypsum ($CaO+SO_3$) and (SO_3) purity of the content.

Samples	$CaO+SO_3$ (%)	SO_3 Purity (%)	Impurities (%)	Water of crystallization (%)
SIG A	73.55	89.93	5.043	21.407
Warake B	72.26	86.97	7.008	20.732
Afuze C	74.53	92.30	4.822	20.648
Aviele D	75.02	93.40	4.330	20.650

Table 5: Elemental Compositions of Dry-Beneficiated SIG, Local Gypsum, and previously studied literature.

Constituents	Strydom et al., (1997)		Ajayi & Dugbe, (2004)					López-Delgado et al., (2014)	SIGA	WB		
	SG	PG	B	G	S	T	IG				AC	AD
SiO_2	0.5	0.5	3.85	5.08	4.00	0.37	2.68	*2.88 – 3.95	2.57	3.35	1.72	1.61
Al_2O_3	0.4	0.1	1.55	1.56	1.19	0.14	0.81	*0.85 – 1.10	0.74	1.05	0.72	0.66
Fe_2O_3	0.8	0.1	0.60	0.59	0.49	0.01	0.30	*0.36 – 0.53	0.72	1.05	1.36	1.11
CaO	32.2	31.7	31.30	29.45	30.20	32.36	33.61	*42.10 – 43.31	31.72	31.81	31.60	31.58
MgO	0.6	0.1	0.54	0.56	0.54	0.57	0.60	*2.65 – 4.81	0.81	1.41	0.93	0.88
SO_3	45.4	44.8	40.96	40.15	40.00	44.73	38.66	*46.31 – 49.06	41.83	40.45	42.93	43.44
Combined H_2O	NR	NR	NR	NR	NR	NR	NR	NR	21.41	20.73	20.65	20.65
K_2O	0.04	0.0	0.10	0.13	0.15	0.01	0.40	*0.16 – 0.24	0.11	0.11	0.07	0.07
Na_2O	0.0	0.04	0.02	0.00	0.1	0.00	0.01	NR	0.09	0.03	0.02	0.00
Cl	0.00	0.00	NR	NR	NR	NR	NR	NR	0.003	0.008	0.002	0.00

*values are dependent on particle size; NR – Not reported; SG & PG – Synthetic & Phosphogypsum; B, G, S, T, IG – Borno, Gombe, Sokoto, Thailand, and England sourced gypsum; SIGA – Spain imported gypsum A, WB – Warake B, AC – Afuze C & AD – Aviele D.

The dry beneficiated SIGA gypsum sample is slightly purer than the Warake B gypsum sample, as seen in Table 4 and is within the required percentage content of gypsum for cement production (85-90%), according to Uriah (2016). SIG sample has an active component of 73.55% and SO_3 purity of 89.93% with combined impurities (SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and Cl) of 5.043% and water of crystallization of 21.407%. Warake gypsum sample shows similar characteristics with 72.26% active component, 86.97% SO_3 purity, 7.008% combined impurities and 20.732% water of crystallization. The number of active components present in the gypsum and the high percentage of SO_3 indicate its purity and effectiveness in regulating cement setting time, and the above results correspond to the report findings by Muhammad *et al.* (2021). The presence of a high percentage of CaO and SO_3 content in Table 3, in comparison with those standard values, shows that the major components in gypsum are Calcium oxide and Sulfur trioxide while minimizing the presence of other compounds as impurities when considering gypsum for cement production.

3.2.1.2 Wet-Beneficiated Local Gypsum XRF Analysis

The elemental compositions and active components of wet-beneficiated local gypsum using X-ray fluorescence spectrometry are shown in Tables 6 and 7.

Table 6: Elemental Compositions of Wet-Beneficiated Local Gypsum

Elemental Compositions	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)	Cl (%)
Warake B1	1.19	0.37	0.60	32.85	1.30	0.06	0.03	42.60	0.006
Afuze C1	0.35	0.31	0.70	32.24	0.87	0.04	0.00	44.38	0.002
Aviele D1	0.37	0.30	0.59	32.38	0.83	0.04	0.01	44.38	0.003

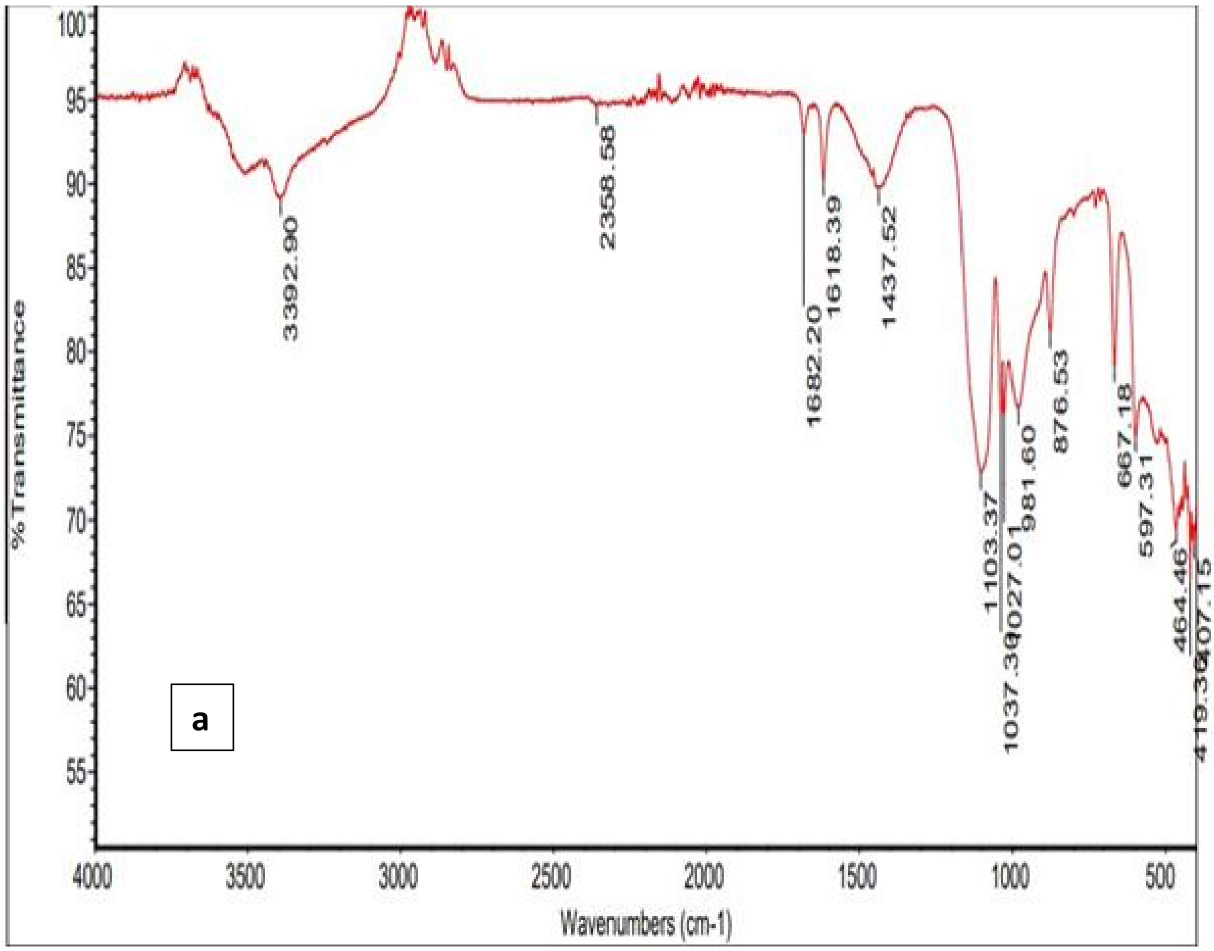
Table 7: Active Components of Wet-Beneficiated Local Gypsum ($CaO+SO_3$) and Purity of the SO_3 Content.

Samples	$CaO+SO_3$ (%)	SO_3 purity (%)	Impurities (%)	Water of crystallization (%)
Warake B1	75.45	91.59	3.556	20.994
Afuze C1	76.63	95.44	2.272	21.098
Aviele D1	76.76	95.42	2.143	21.097

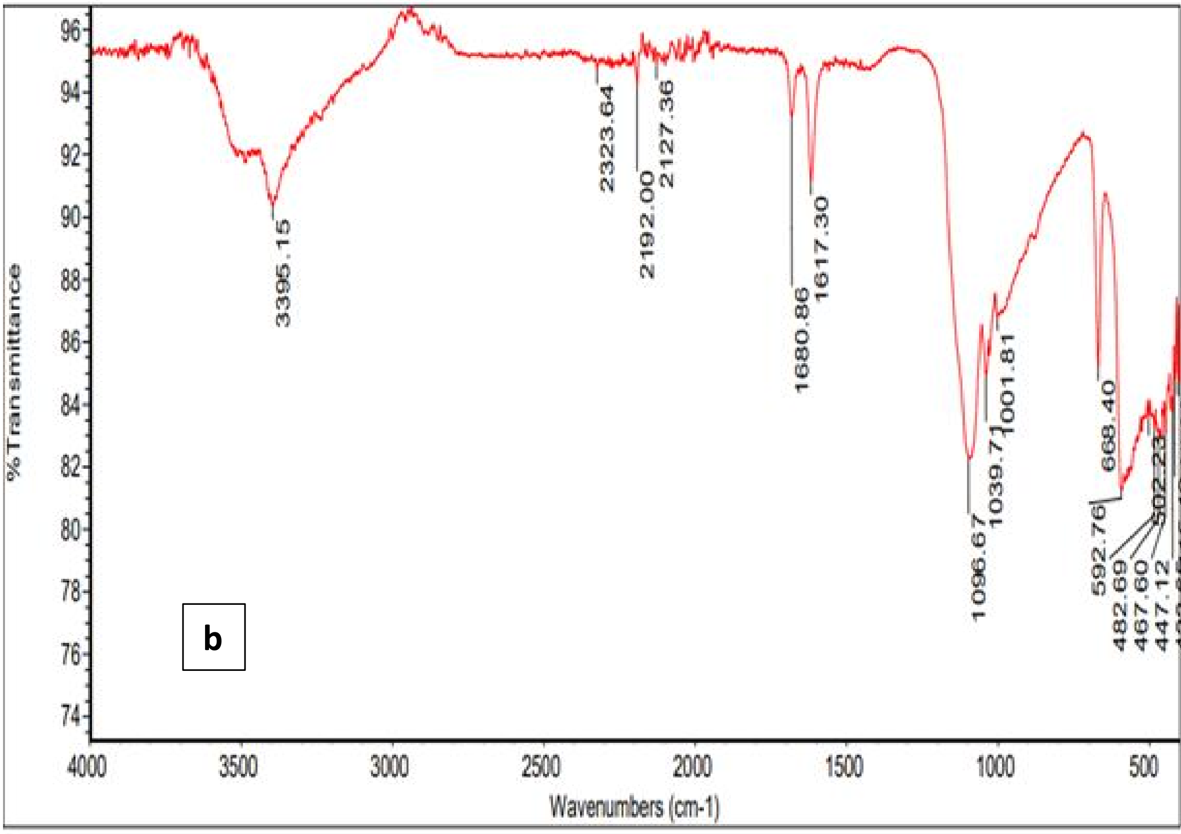
Wet-beneficiation reduced impurities in locally sourced gypsum, as shown in Table 6, with a subsequent increase in purity due to water washing. The results, when compared with previous studies from literature in Table 5, showed that Warake gypsum (B1) exhibited 32.85 % CaO, 42.60 % SO_3 and 75.45 % active component, influencing cement setting time. Impurities dropped from 7.008 % to 3.556 %, while the active component and SO_3 purity increased, as seen in Table 7. Afuze gypsum (sample C1) displayed 32.24 % CaO and 44.39 % SO_3 with 76.63 % active component. Similar findings were reported by Moalla *et al.* (2017) and Wang *et al.* (2020). Aviele gypsum exhibited analogous improvements, including higher SO_3 purity and lower impurities after wet-beneficiation. The purity level of the local gypsum after wet-beneficiation with water shows a remarkable improvement, and this confirmed the reported findings of Adams *et al.* (2021). In conclusion, local gypsum outperformed SIG counterparts in both dry and wet-beneficiated forms. This highlights the benefits of wet-beneficiation in increasing gypsum purity and discouraging gypsum importation.

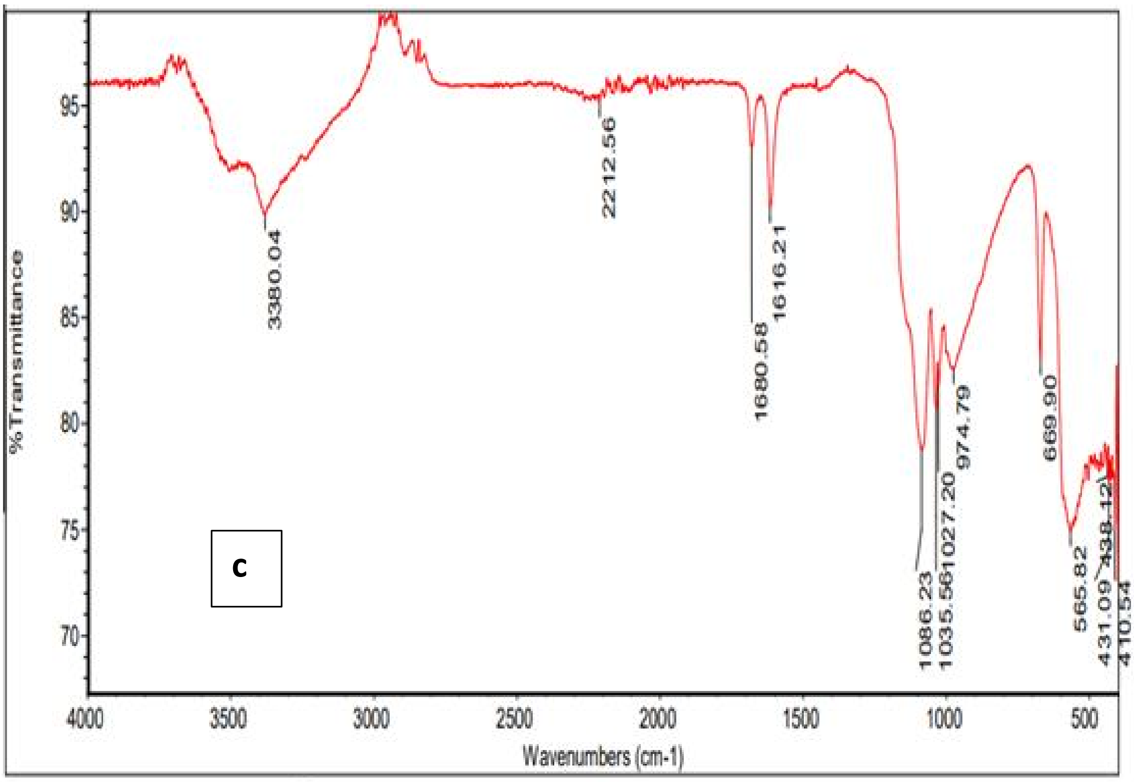
3.2.2 FTIR analysis

Figure 1(a, b, c, and d) below shows the FTIR spectra of the dry-beneficiated Spain Imported & local gypsum samples. Significant absorption peaks were seen in the dry-beneficiated Spain gypsum, as shown by the different functional groups. The functional groups present include (−COOH) group, hydroxyl (−OH) group, cyano (−C≡N) group with strong C≡N stretch, carbonyl (−C=O) group with strong C=O, amide ($CO-NH_2$) group with medium to strong N−H stretch, ethoxy group (−OR) with medium to strong (C−O and =C−O−C symmetric), halides group with strong C−F, C−Br and C−I stretch, and stretching band linking to C=C and −C≡C− functional groups. Similar functional groups were observed for the Warake gypsum sample. This observation agrees with the findings reported by Akhabue *et al.* (2020) and Xiaodi et (2022*).*


%Transmittance
Wavenumbers (cm-1)
3392.90
2358.58
1682.20
1618.39
1437.52
1103.37
1037.30
1027.01
981.60
876.53
667.18
597.31
464.46
419.30
407.15
a

.





Similar functional groups were observed for the wet-beneficiated local gypsum samples at different wavenumbers from those of the dry-beneficiated.

When the occurring functional groups interact with clinker minerals and other positively charged components during cement blending, these diverse functional groups in dry-beneficiated Spain and Warake gypsum enable chemical reactions and excellent homogeneity (Xiaodi *et al.,* 2022). These polar, hydrophilic functional groups improve cement's ability to bind water and hydrate it during chemical reactions. These functional groups interact with other gypsum constituents, including MgO, CaO, and SO_3, to produce hydrated salts (Ma *et al.,* 2021).

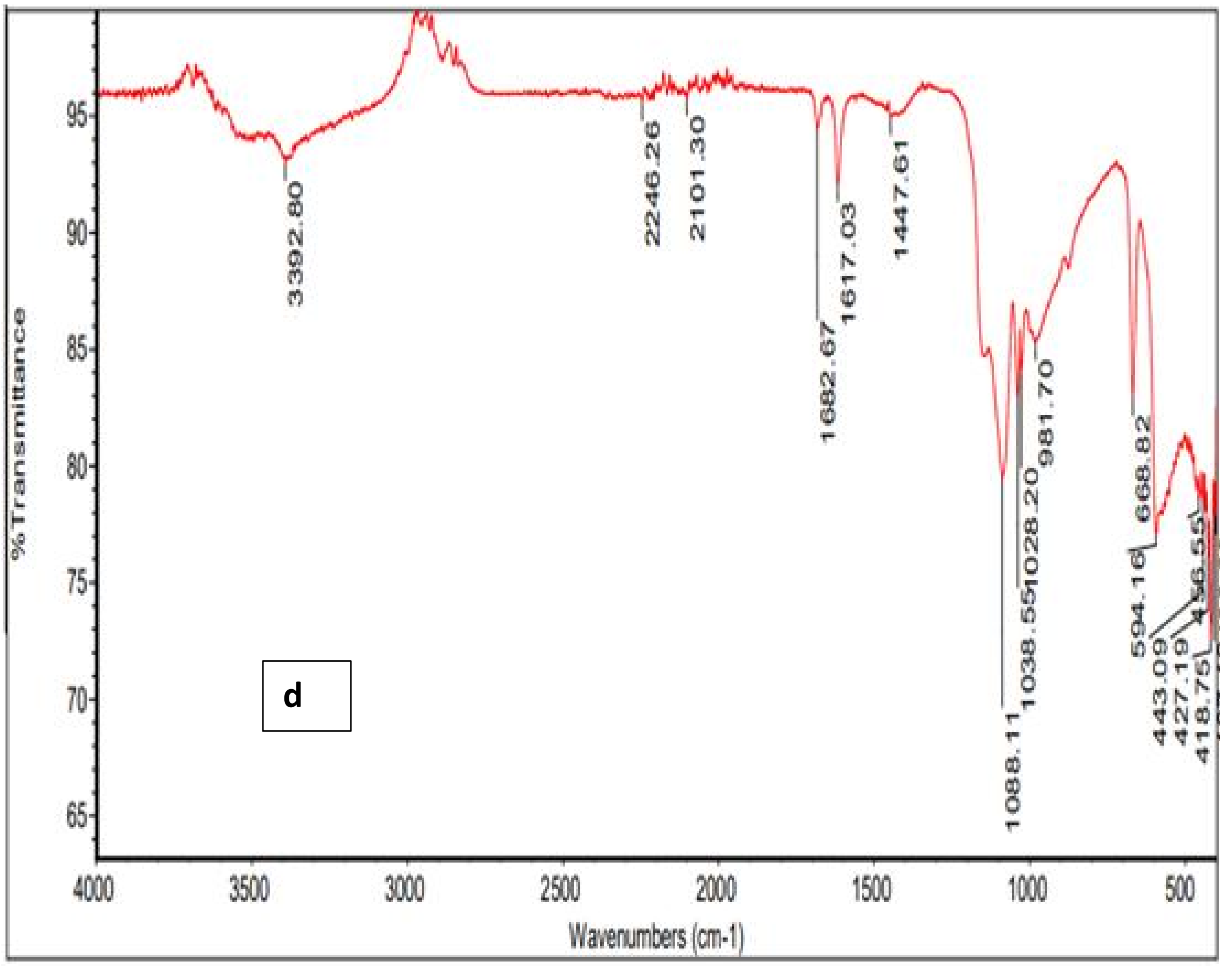


Figure 1: FTIR Spectra of Dry-beneficiated (a)Imported Gypsum, (b)Warake Gypsum, (c)Afuze Gypsum and (d)Aviele Gypsum Samples

The functional groups in the dry-beneficiated and wet-beneficiated local gypsum samples remained unchanged, though the wavenumbers decreased in values after wet-beneficiation. The polarity and hydrophilic nature of these functional groups in gypsum create a medium for the ionic interactions with the positively charged clinker minerals (C_2S, C_3S, C_3A, C_4AF). These ease the hydration process, thereby giving enough time for chemical reaction, homogenization and proper regulating of the setting time of the cement (Xiaodi *et al.,* 2022).

4 COST ANALYSIS FOR LOCAL GYPSUM PRODUCTION

The cost analysis of both SIG and locally sourced gypsum was done in line with the principles and fundamentals highlighted in plant design (Towle & Sinnott, 2008). Table 8 shows the cost of importing SIG to Nigeria.

Table 8: Cost of Imported Gypsum

Ton	Value (₦)	Cost of Transportation (₦/ton)	Value (₦/ Ton)
1.00	64,231.09	17,000.00	47,231.09

A unit (1 ton) of gypsum cost ₦47,231.09 in the year 2022, while the cost of transportation within the country is ₦ 17,000.00. Therefore, the cost of Spain's imported gypsum, including the cost of transportation within Nigeria, is ₦ 64,231.09.

4.1 Cost of Local Gypsum

The cost of producing locally sourced gypsum from the beginning of the land purchase license to startup operations is highlighted in this study. This cost is in line with the principles and fundamentals highlighted in plant design (Towle & Sinnott, 2008). Table 9 illustrates the cost of production of local gypsum at the time of carrying out this study.

10.51975/24390207.som
Journal of the Nigerian Society of Chemical Engineers, 39(2), 2024

Table 9: Overall production cost for Local Gypsum in Edo State

S/N	Item	Quantity	Cost/Unit (₦)	Cost/Month (₦)	Cost/Year (₦)
1	**LAND**				
i	Procurement and development		50,000,000.00	50,000,000.00	50,000,000.00
2	**EQUIPMENT/INSTALLATION**				
i	Grader	2	75,000,000.00	150,000,000.00	150,000,000.00
ii	Drilling Machines	2	50,000,000.00	100,000,000.00	100,000,000.00
iii	Dump Trucks	10	42,000,000.00	420,000,000.00	420,000,000.00
iv	Hydraulic Excavators	2	75,000,000.00	150,000,000.00	150,000,000.00
v	Wheel loader	4	55,000,000.00	220,000,000.00	220,000,000.00
vi	Jaw Crusher	1	23,000,000.00	23,000,000.00	23,000,000.00
vii	Hammer Milling Machine	1	8,000,000.00	8,000,000.00	8,000,000.00
viii	Conveyors	1	6,000,000.00	6,000,000.00	6,000,000.00
ix	Bulldozer	2	70,000,000.00	140,000,000.00	140,000,000.00
x	Hopper and Screen	1	3,000,000.00	3,000,000.00	3,000,000.00
	Total Cost of Equipment			**1,220,000,000.00**	**1,220,000,000.00**
3	**COST OF INSTALLATION**				
i	Installation of Equipment		20,000,000.00	20,000,000.00	20,000,000.00
	Total Cost of Installation			**20,000,000.00**	**20,000,000.00**
4	**CIVIL/DESIGN**				
i	Design and Civil		50,000,000.00	50,000,000.00	50,000,000.00
	Total Cost of Design and Civil			**50,000,000.00**	**50,000,000.00**
5	**COST OF OFFICE VEHICLES**				
i	Office Hilux	3	15,000,000.00	45,000,000.00	45,000,000.00
ii	Office Bus	2	20,000,000.00	40,000,000.00	40,000,000.00
	Total Cost of Official Vehicles			**85,000,000.00**	**85,000,000.00**
6	**OFFICE, FURNITURE AND FITTINGS**				
i	6 Bedroom flat Building	1	12,000,000.00	12,000,000.00	12,000,000.00

S/N	Item		Quantity	Cost/Unit (₦)	Cost/Month (₦)	Cost/Year (₦)
ii	Office Chairs		20	15,000.00	300,000.00	300,000.00
iii	Air conditioning		6	150,000.00	900,000.00	900,000.00
iv	Office Printers		4	130,000.00	520,000.00	520,000.00
	Total Cost of Office, Furniture				**13,720,000.00**	**13,720,000.00**
7	**COST OF MANPOWER**					
i	Quarry Manager		1	400,000.00	400,000.00	4,800,000.00
ii	Mining Engineers		2	200,000.00	400,000.00	4,800,000.00
iii	Geologists		2	200,000.00	400,000.00	4,800,000.00
iv	Accountants		2	150,000.00	300,000.00	3,600,000.00
v	Sales		2	190,000.00	380,000.00	4,560,000.00
vi	HR/Admin		2	190,000.00	380,000.00	4,560,000.00
vii	Operators		10	100,000.00	1,000,000.00	12,000,000.00
viii	Drivers		6	70,000.00	420,000.00	5,040,000.00
ix	Driller Man		2	90,000.00	180,000.00	2,160,000.00
x	Blaster man		4	100,000.00	400,000.00	4,800,000.00
xi	Security		10	100,000.00	1,000,000.00	12,000,000.00
xii	Cleaners		4	40,000.00	160,000.00	1,920,000.00
	Total Cost of Manpower				**5,420,000.00**	**65,040,000.00**
8	**COST OF UTILITIES**					
i	AGO	₦ 800/L	20,000.00	800.00	16,000,000.00	192,000,000.00
ii	Petrol	₦ 270/L	2,000.00	270.00	540,000.00	6,480,000.00
iii	Electricity			4,000,000.00	4,000,000.00	48,000,000.00
iv	Water expenses			1,000,000.00	1,000,000.00	12,000,000.00
	Total Cost of Utilities				**21,540,000.00**	**258,480,000.00**
9	**COST OF EXPLOSIVES**					
i	Ammonium nitrate	₦ 2000/KG	200.00	2,000.00	400,000.00	4,800,000.00
ii	Dynacord	₦350/Meter	4,000.00	350.00	1,400,000.00	16,800,000.00
iii	Electric Detonator	₦ 1200/pc	4,000.00	1,200.00	4,800,000.00	57,600,000.00

10.51975/24390207.som

Journal of the Nigerian Society of Chemical Engineers, 39(2), 2024

S/N	Item		Quantity	Cost/Unit (₦)	Cost/Month (₦)	Cost/Year (₦)
iv	High Gelatine	₦2300/KG	10,000.00	2,300.00	23,000,000.00	276,000,000.00
	Total Cost of Explosives				**29,600,000.00**	**355,200,000.00**
10	**STARTUP COST /MISCELLANEOUS**					
	Miscellaneous			10,000,000.00	10,000,000.00	120,000,000.00
	Cost of Miscellaneous				**10,000,000.00**	**120,000,000.00**
	TOTAL COST OF PRODUCTION PER YEAR				**1,505,280,000.00**	**2,237,440,000.00**

Considering large-scale mining of local gypsum especially in Edo state, the cost of production per ton of the local gypsum as at the time of carrying out this research is summarised in Table 9. This cost is done considering the current Nigeria's 2022 economy. This costing covers land and land development, equipment, installation, civil/design, cost of official vehicles, office furniture and fittings, cost of workforce, cost of utilities, cost of explosives for blasting and startup/miscellaneous costs. Since gypsum processing involves excavating, crushing, screening and grinding, the need for the purchase of the equipment, as mentioned earlier, is necessary. This gives a total cost of production of two billion, two hundred and thirty-seven million, four hundred and forty-four thousand naira only per year while the cost of production per month is one billion, five hundred and five million, two hundred and eighty million naira only for new investment on a largescale production.

4.2 Sales of Local Gypsum

The sales of the local gypsum after production on a large scale are highlighted to determine the profit margin per ton of gypsum. Table 10 shows the sales at a unit price of ₦35,000.00 per ton of the local gypsum.

Table 10: Sales of Local Gypsum

S/N	Description	Quantity	Amount ₦
i	Number of trucks per day	19.00	
ii	Number of trucks per month (19 Trucks x 30 days)	570.00	
iii	Average tonnage per truck	35.00	
iv	Sales unit price per ton		35,000.00
v	Sales for a day (19 trucks x ₦35,000 x35)		23,275,000.00
vi	Sales for a month (570 Trucks x 35Tons x ₦35,000)	30.00	698,250,000.00
vii	Sales for a year (340 days x 19 Trucks x35Tons x ₦35,000)	340.00	7,913,500,000.00
viii	Gross profit per year (Total sales/yr. - total cost of prod/yr.)		5,676,060,000.00
	Cost of Producing 1 Ton		
i	Total tonnage per year (19 trucks x 340 days x 35tons)	226,100.00	
ii	Cost of production per year		2,237,440,000.00
iii	Cost of producing 1 Ton (Cost of prod/yr. / Tons/yr.)		9,895.80
	Profit Margin		
i	Profit margin per Ton (Sales unit price - Cost of prod/tons)		25,104.20

From the production and sales analysis of all the locally sourced gypsum in comparison with the cost of importation of gypsum, it is imperative to note that producing gypsum on a large scale in Nigeria, including transportation to proximate cement industries in Nigeria, will be more viable. Therefore, it is preferable to buy locally sourced gypsum at the selling price of ₦35,000.00 than depending on imported gypsum at the cost of ₦64,231.09, including the cost of transportation.

5.0 CONCLUSION

Gypsum samples from both imported and local sources were prepared using dry and wet-beneficiation methods to determine their moisture content, eliminate impurities, and prepare the desired hemihydrate. XRF, XRD, BET, and FTIR characterizations of the local gypsums showed that the elemental composition, surface chemistry, functional groups, and textural qualities were similar to those of the imported Spanish gypsum and better than other gypsums obtained from other countries, as shown from various studies. The cost analysis of the entire production and sales process narrowed down to the profit margin of local production per tonne of gypsum produced and sold, showed a profit margin of ₦25,104.20 per tonne of local gypsum sold to cement manufacturers at the 2022 purchase index compared to the cost of gypsum imported from Spain by manufacturers. This indicates that local gypsum samples are a viable substitute for imported Spanish gypsum in the production of cement due to the required quality, compliance with purity standards, and cost efficiency.

REFERENCES

Abdul-Wahab, S. A., Al-Dhamri, H., Ram, G., and Chatterjee, P. V. (2021). An overview of alternative raw materials used in cement and clinker manufacturing. *International Journal of Sustainable Engineering*, 14(4), 743–760.

Adams, L. A., Enobong, Reginald. E., Taiwo, A., Stella, O., and John, M. (2021). Facile purification of Warake mined gypsum and its use for preparing nano-hemihydrates. *Journal of Metals, Materials and Minerals*, 106110.

Ahmad, A. (2021, July 6). Comminution a heart of mineral processing. Retrieved February 5,2023,fromTechnologyTimeswebsite:https://www.technologytimes.pk/2021/07/06/comminution-a-heart-of-mineral-processing/

Ajayi, O. O., & Dugbe, S. A. (2004). Chemical Analysis of some Nigerian Gypsum and Limestone Samples Utilized by a Leading Cement Manufacturing Industry. *Global Journal of Pure and Applied Sciences*, *10*(1), 87–90. https://doi.org/10.4314/gjpas.v10i1.16363.

Akhabue, E. C., Evidence, O. O.-B., Eghe, A. O., and Otoikhian, S. K. (2020). Development of a bio-based bifunctional catalyst for simultaneous esterification and transesterification of neem seed oil: Modeling and optimization studies. *Renewable Energy*, *152*(2020), 724–735.

Al-Ridha, A. S. D., Abbood, A. A., Elaiwi, E. H., Hussein, H. H., and Dheyab, L. S. (2020). Increasing the setting time of Warake gypsum (Joss) by the use of TGP additive. *IOP Conference Series: Materials Science and Engineering*, *888*(1), 012078.

Amenaghawon, N. A., Nelson, I. E., and Kessington, O. (2021). Optimum biodiesel production from waste vegetable oil using functionalized cow horn catalyst: A comparative evaluation of some expert systems. *Cleaner Engineering and Technology*, *4*(100184), 1–14.

ASTM D792: Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement. (2020, July 29). https://www.astm.org/standards/d792

ASTM-C471 | Chemical Analysis of Gypsum & Gypsum Products, Standard Testmethods For | Document Center, Inc. (1991, February 22). [ASTM C471]. https://www.document-center.com/standards/show/ASTM-C471

Bouzit, S., Laasri, S., Taha, M., Laghzizil, A., Hajjaji, A., Merli, F., and Buratti, C. (2019). Characterization of natural gypsum materials and their composites for building applications. *Applied Sciences*, *9*(2443), 15. https://doi.org/doi:10.3390/app9122443

Cordon, H. C. F., Ferreira, M. S., and Ferreira, F. F. (2021). Comparative analysis of recycled plaster composition determined by X-ray powder diffraction and thermogravimetric analyses. *Construction Materials*, 1(2), 105–121.

Dafni, F., Stergios, A., Eleni, V., Elias, V., Costas, P., Stephen, O., and Geofrey, D. (2019). Microstructure and compressive strength of gypsum-bonded composites with papers, paperboards and Tetra Pak recycled materials. *Journal of Wood Science*, *65*(42), 1–8.

Dogara, M. D., and Aloa, J. O. (2017). Preliminary estimate of gypsum deposit based on Wenner and Schlumberger electrical resistivity methods at Ikpeshi, Edo State, Nigeria. *Science World Journal*, *12*(2).

Ghumman, S. A., Mahmood, A., Noreen, S., Rana, M., Hameed, H., Ijaz, B., and Rehman, M. F. (2022). Formulation and evaluation of quince seeds mucilage – sodium alginate microspheres for sustained delivery of cefixime and its toxicological studies. *Arabian Journal of Chemistry*, *15*(6), 103811.

Gunnar, H., and Kristine, K. (2020, September 23). Beneficiation of raw gypsum ore. Retrieved January 21, 2023, from 2021 SURP Symposium website: https://surp.calpoly.edu/2020/beneficiation-of-raw-gypsum-ore/

James, O. O., Mesubi, M. A., Adekola, F. A., Odebunmi, E. O., and Adekeye, J. I. D. (2008). Beneficiation and Characterization of a bentonite from North-Easter Nigeria. *Journal of the North Carolina Academy of Science*, *124*(4), 154–158.

Layr, K., and Hartlieb, P. (2019). Market analysis for urban mining of phosphogypsum. *BHM Berg- Und Hüttenmännische Monatshefte*, *164*(6), 245–249.

López-Delgado, A., López-Andrés, S., Padilla, I., Alvarez, M., Galindo, R., & José Vázquez, A. (2014). Dehydration of Gypsum Rock by Solar Energy: Preliminary Study. *Geomaterials*, *04*(03), 82–91. https://doi.org/10.4236/gm.2014.43009.

Ma, H., Chen, S., Song, Y., Yin, D., LI, X., and Li, X. (2021). Experimental investigation into the effects of composition and microstructure on the tensile properties and failure characteristics of different gypsum rocks. *Scientific Reports*, *11*(14517), 1–13.

Moalla, R., Gargouri, M., Khmiri, F., Kamoun, L., and Zairi, M. (2017). Phosphogypsum purification for plaster production: A process optimization using full factorial design. *Environmental Engineering Research*, 1–29. https://doi.org/10.4491/eer.2017.055.

Mohamad, N., Muthusamy, K., Embong, R., Kusbiantoro, A., and Hashim, M. H. (2022). Environmental impact of cement production and solutions: A review. *Materials Today: Proceedings*, *48*, 741–746.

Mohammad, A., Hoang, N., Tapio, F., Harisankar, S., Ville-Veikko, T., Anu, K., and Paivo, K. (2022). On the hydration of synthetic aluminosilicate glass as a sole cement precursor. *Cement and Concrete Research*, *159*(106859), 1–12. https://doi.org/doi.org/10.1016/j.cemconres.2022.106859

Muhammad, A. D., Amartey, Y. D., Kaura, J. M., Ijimdiya, T. S., and Lawan, A. (2021). Effect of Warake sourced Nigerian Gypsum on the strength and microstructure of portland cement mortar. *Nigerian Journal of Technology*, *39*(4), 1001–1010.

Onat, L. O., Valiyev, K. R., Agapov, R. V., and Kangarli, L. M. (2016). Analysis of anhydrite's effects on quality of cement. *International Research Journal of Engineering and Technology*, 03(09), 7.

Randazzo, L.; Montana, G.; Hein, A.; Castiglia, A.; Rodonò, G.; Donato, D.I. Moisture absorption, thermal conductivity and noise mitigation of clay based plasters: The influence of mineralogical and textural characteristics. *Appl. Clay Sci.* 2016, 132–133, 498–507

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. (2019, March 19). [Html]. https://www.astm.org/d2216-19.html

Strydom, C. A., Groenewald, E. M., & Potgieter, J. H. (1997). Thermogravimetric studies of the synthesis of cas from Gypsum, CaSo4·2H2O and phosphogypsum. *Journal of Thermal Analysis*, *49*(3), 1501–1507. https://doi.org/10.1007/BF01983709.

Towle, W., & Sinnott, R. K. (2008). Chemical engineering design: Principles, practice and economics of plant and process design. Elsevier/Butterworth-Heinemann.

Uriah, L. (2016). Warake sourcing of gypsum for industrial utilization in Nigeria. *Nigeria Society of Chemical Engineers Conference,* 46, 23-32.

Wang, J., Dong, F., Wang, Z., Yang, F., Du, M., Fu, K., and Wang, Z. (2020). A novel method for purification of phosphogypsum. *Physicochemical Problems of Mineral Processing*, *56*(5), 975–983. https://doi.org/10.37190/ppmp/127854

Xiaodi, D., Serdar, A., Mert, Y. Y., and Geert, D. S. (2022). Early structural build-up, setting behavior, reaction kinetics and microstructure of sodium silicate-activated slag mixtures with different retarder chemicals. *Cement and Concrete Research*, *159*(106872), 1–15.

Zmemla, R., Chaurand, P., Benjdidia, M., Elleuch, B., and Bottero, J. Y. (2016). Characterization and pH Dependent Leaching Behavior of Tunisian Phosphogypsum. *American Scientific Research Journal for Engineering, Technology, and Sciences*, *24*(1), 230–244.