Investigation of Locally Sourced Sand as Proppants in Hydraulic Fracturing Operations

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Abstract

Hydraulic fracturing is a critical reservoir stimulation technique that enhances hydrocarbon recovery by generating fracture networks to facilitate fluid flow from the reservoir to the wellbore. While conventional proppants effectively support fracture conductivity, their high cost drives the need for alternative, cost-efficient options. This study evaluates the potential of natural sands as economical proppants for hydraulic fracturing. The sands were characterized using X-ray fluorescence (XRF) to assess their chemical composition and mechanical properties. To improve strength and minimize fines generation, locally sourced sands were coated with epoxy resin. An economic analysis was conducted to determine the feasibility of employing these sands in field operations. The findings demonstrate that quartz and topaz sands meet API ISO standards and are viable alternatives for hydraulic fracturing applications, offering a balance of performance and cost-effectiveness.

Introduction

In response to the challenges posed by traditional proppants, there is growing interest in exploring locally sourced sands as an alternative proppant material. By sourcing proppants locally, operators can reduce transportation costs and minimize the environmental impact associated with long distance transport. Therefore, leveraging on indigenous sands as proppant in Nigeria for hydraulic fracturing, suggests a potential viable solution to reduce dependence on imports, create local content economic opportunities, and mitigate operational costs.

Hydraulic fracturing, or fracking, has become a cornerstone technology for extracting oil and natural gas from unconventional reservoirs, such as shale formations (Moghadasi et al., 2019; Ifeanyichukwu et al., 2024). This process involves injecting a high-pressure fluid mixture—comprising water, sand, and chemical additives—into subsurface rock formations (Taylor et al. 2009). The applied pressure induces fractures in the rock, facilitating the release of trapped hydrocarbons and enabling their flow to the surface for recovery. Over recent decades, hydraulic fracturing has significantly increased global energy reserves and transformed the oil and gas industry (Rojas et al. 2023). A critical component of this process is the use of proppants, granular materials introduced into the fractures to maintain their openness after hydraulic pressure is withdrawn (Soane et al. 2011). Proppants maintain the fractures open, creating permeable pathways that enable hydrocarbons to flow from the reservoir to the wellbore. Without proppants, fractures would rapidly close under the surrounding rock pressure, significantly impeding hydrocarbon flow (Bandara et al. 2022). Common proppant materials include sand, ceramic particles, and resin-coated materials, with sand being the most widely used globally due to its abundance, cost-effectiveness, and favorable physical properties (Wahab et al. 2022; Tang et al. 2018). However, advancements in hydraulic fracturing technologies and the growing need for higher efficiency have spurred interest in alternative proppant materials and sourcing strategies (Mohamad-Sobri 2013). The high cost of conventional proppants often escalates

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oil production expenses, whereas locally sourced sands, derived from nearby geological formations, present an economical and practical alternative to imported sands (Gaber and Ibrahim 2020).

Furthermore, utilizing locally sourced sands can bolster regional economies and enhance supply chain resilience by reducing reliance on external suppliers (Agrawal and Gernand 2020; Zwalatha et al. 2024). Zwalatha et al. investigated the suitability of Luwa sands for use as proppants in hydraulic fracturing operations. The sands were collected from the Luwa River in Toro, Bauchi State, Nigeria, and coated with epoxy resin to enhance their properties. Experimental evaluations were conducted following API-recommended practices to assess the sand's potential as a proppant. Characterization results demonstrated that Luwa sand meets the requirements for use as a proppant and performs competitively against international standards. Additionally, Wahab et al. (2022) noted that sands composed predominantly of silica grains are the most suitable naturally occurring materials for proppants in hydraulic fracturing processes. Gaber and Ibrahim (2021) analyzed pure silica sands along the Red Sea coast of Sinai and the Eastern Desert for their suitability as fracturing sands. Their study focused on Wadi Dakhal white sand and sand dunes found along the Bahariya Oasis Road (Karama oil field). Results showed that the silicon dioxide ($SiO2$) content was 99% for Wadi Dakhal and 95% for Karama field sands. The sands exhibited crush resistance in the range of 5500–6500 psi, turbidity at 2%, and rounded to sub-rounded grain shapes, aligning with ISO 13503-2 standards. The grain size distribution ranged between 30/50 and 40/70 mesh (710 µm to 210 µm). Similarly, Elochukwu and Kenneth (2020) investigated Baram and Tanjung sands for potential use as proppants. Baram sand, with its larger grain size, was found to support high permeability under low closure stress, making it suitable for hydraulic fracturing at shallow depths.

Building on this foundation, the current research focuses on a comprehensive evaluation of the characterization, performance, and economic viability of Quartz and Topaz sands as proppants for hydraulic fracturing operations.

Materials and Methods

This study utilized quartz sand, topaz sand, resin-hardener, and various laboratory instruments, including a high-precision analytical balance, a hydraulic universal testing machine, and an EDXRF system for elemental analysis. Hydrochloric acid and ammonium bifluoride were used as reagents in sample preparation. Measurements focused on assessing sand properties such as density, particle size, and composition, carried out under controlled laboratory conditions.

Collection of materials. The topaz and quartz sands are sand deposit in the Agwatashi river situated in the Obi local government area of Nasarawa State in Nigeria at latitude 8º22” N and longitude 8º46” E with a climate type of wet tropical Savanna. A field trip of the Agwatashi river was carried out and the obtained sands were characterized in the laboratory to evaluate the potential use as proppant in hydraulic fracturing operations. **Figure 1** is a sample of quartz and topaz sands.

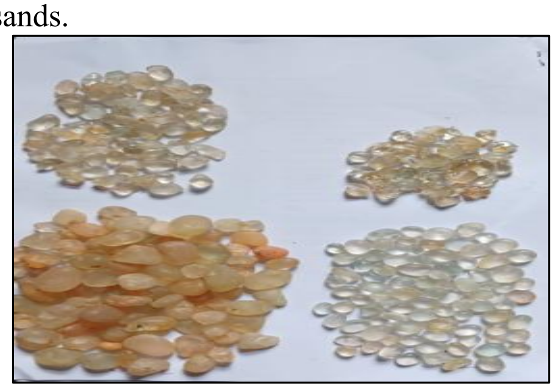

Figure 1—Sample of the sands.

Sample Preparation. The sand (quartz and topaz) was collected and classified for laboratory testing and characterization. The samples were washed, dried, and weighed. The sand sample was weighed prior to washing to remove impurities and contaminants. It was re-weighed to determine the loss of contaminants in percent and ensure it was bacterial free for characterization.

Characterization of the Sands. The locally sourced sands were characterized to determine their suitability as a proppant. This followed the standard protocols known as API STD 19C (2018). Recommended Practice (API RP 56) and Standard Organisation for Standardization (ISO 13503-2) recommendation.

X-ray Fluorescence (XRF). X-ray fluorescence (XRF) was used to investigate the elemental composition of the samples. X-ray fluorescence was conducted on the sands (quartz and topaz) under helium (He) atmosphere using palladium (Pd) X-ray tube at a voltage of 60 kV and current 10µA with 10 mm beam spot size, and silicon (Si) drift detector comprised of Peltier electronic circuit cooling system. Elemental detection limits from low parts-per-million (ppm) to high weight percent (%wt.). The sands are put into the machine, and then the machine starts to rotate. As it rotated, the elemental structure of the sands was being displaced on the computer screen.

Sieve Test. Sieve analysis was conducted to assess the particle size distribution of granular materials and to ensure a consistent methodology for sieve evaluation. Sieve analysis was conducted by allowing the sand to pass through a series of sieves of progressively smaller mesh size and weighing the amount of sand that is stopped by each sieve as a fraction of the whole mass (Martins et al. 2021). The equipment and materials used for the sieve analysis procedure include the following: Sieve sets, STSJ-4A high frequency sieve shaker, weighing balance and brushes. Sieve test of mesh size 20/40 was prepared. The essence of the 20/40 mesh sand is to obtain sand particles that fall within the diameter size range of (850 µm-425 µm). This was achieved using sieve stack in order of decreasing sieve openings of 16 (1.180 mm), 20 (0.850 mm), 25 (0.710 mm), 30 (0.600 mm), 35 (0.500 mm), 40 (0.425 mm), and 50 (0.300 mm). The sieve test was conducted to get sand within the range of 850 µm-425 µm (20/40 mesh) size.

Sphericity and Roundness. Sphericity and Roundness Test were conducted to evaluate the degree at which the sands approximate the shape of a perfect sphere. However, the roundness procedure was done to measure the sharpness of the sand's edges and corners. Sphericity and roundness tests are conducted to evaluate the proppant shapes. The most common used method of determining roundness and sphericity is the use of the Krumbein/Sloss chart as shown in **Figure 2**. In this study, twenty (20) individual particles were randomly selected for evaluation of particle sphericity and roundness. The sphericity of each selected particle was determined by comparison to the Krumbein/Sloss chart. The corresponding number of sphericities for each particle selected was observed. The arithmetic average of the recorded sphericity numbers was calculated and reported as average particle sphericity to the nearest 0.1 unit. The roundness value for each of the selected particles was determined using the same procedure as for the sphericity measurement. In addition, the arithmetic average of the recorded roundness numbers was evaluated and recorded as the average particle roundness of sand to the nearest 0.1 unit.

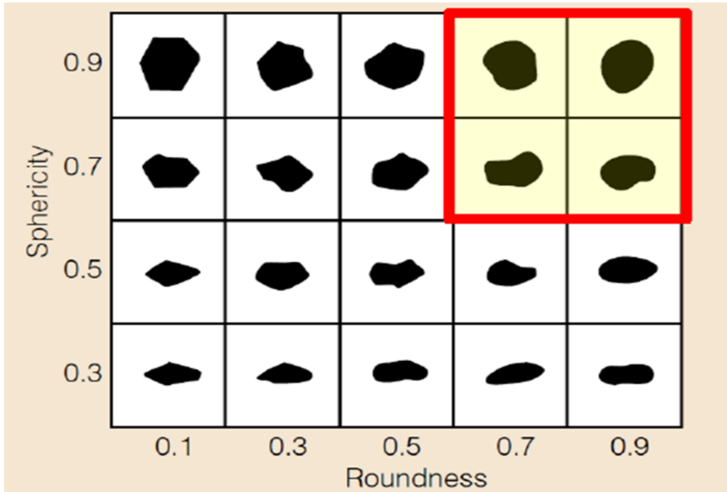

Figure 2—Chart for Estimation of Sphericity and Roundness (API> 0.6).

Acid Solubility. The acid solubility test was conducted to examine the suitability of a proppant for use in applications where the proppant can encounter acids. The preferred method of testing acid solubility was the use of a solution of 12:3 HCI: HF acid (12% by mass of HCI and 3% by mass of HF) (API STD 19C). The solubility of a proppant in 12:3 HCI: HF showed that the number of soluble materials (carbonates, feldspars, iron oxides, clays) present in the proppant. The method of preparation of a solution of 12:3 HCI: HF acid involved the addition 47.2g of pure NH4F2 to 500 ml of distilled water in a 1000 ml graduated cylinder. 361 ml of a 37% HCl was added to the mixture in the cylinder and diluted to 1000 ml with distilled water. The mixture was stirred to ensure complete mixing. The resulting mixture is the prepared 12:3 HCl: HF acid that was used for the test. The percentage of mass dissolved in the acid is calculated by **Eq. (1)**,

$$S = \frac{m_S + m_f + m_{sf}}{m_s} x\ 100 \qquad (1)$$

where, S represents the acid solubility (in %), ms denotes the mass of the sand sample (in grams), m_f refers to the mass of the filter paper (in grams), and m_{fs} is the mass of the dried filter paper along with the sand sample (in grams).

Turbidity. Turbidity test was conducted to evaluate the number of suspended particles or other finely divided matter present in the sand. Turbidity tests measure an optical property of a suspension that results from the scattering and absorption of light by the particulate matter suspended in the wetting fluid (Ismaeel and Tayeb 2024). Turbidity meters of the incident light beam were normal to the detection path of the detector; this is the preferred method of measurement and expressed in Nephelometric turbidity unit (NTU). The turbidity test was conducted by addition of 100 ml of demineralized water to 70 g of the sample in a 250 ml flask. Quartz and topaz sand were allowed to stand in the water for 15 minutes and the flask was put into a shaker bottle. The degree of frequency of the Shaker bottle was set to 7 RPM based on recommended literature, and the bottle was allowed to agitate for 20 seconds. The flask was later removed from the shaker bottle and stood for 5 to 10 minutes. 30 ml of the water and silt suspension was removed from the water volume with the use of a syringe. The suspended-particle sample placed in the test and Palintest calibrated turbidimeter was recorded.

Bulk Density. Bulk Density Test was conducted to evaluate the bulk density of the proposed sands as proppants. The bulk density indicates the mass of the proppants that fills a unit volume. It can be used to evaluate the mass of the proppant needed to fill a fracture. The equipment that was used to determine the bulk density was a calibrated cylinder and a weighing balance. The procedure for the bulk density was determined, and the volume of the cylinder was done by weighing the dry, empty cylinder with a flat glass and the mass. The cylinder was filled with water and a plate moved into contact with the upper edge of the cylinder, cutting off the edge of water in the plane. The glass plate was held firmly, the excess water was removed, and the gross mass was obtained. The bulk density was calculated and expressed in grams per cubic centimeter, shown in **Eq. (2)**,

$$\rho_{bulk} = \frac{m_p}{v_{cyl}} \quad (2)$$

where, m_p is the net mass, expressed in grams, of the sand, equal to $m_{f+p} - m_f$; v_{cyl}, is the volume of the cylinder, expressed in cubic centimetres.

Crush Resistance. Crush resistance tests were investigated on the sands to evaluate the amount of proppant that was crushed at a given stress. Tests are carried out on the sands samples that have been sieved so that all particles tested are within the specified size range specified by the API and ISO recommendation. The amount of proppant crushed at each stress level was measured. The test results provide the indications that the stress level where the proppant crushing was excess and the maximum stress to which the proppant sample should be subjected. A 2500 kN hydraulic universal testing machine, a cell for proppant crush resistance test, test sieves, pan and lid, a weighing balance, a high frequency sieve shaker and a stopwatch was used for the test.

Loss on Ignition (LOI). The loss on ignition (LOI) test was conducted to evaluate the number of combustible materials on the sand. The sands (Topaz and Quartz) were weighed, and their masses recorded. These samples were subjected to heating at 900°C in a furnace for 12 hours, the samples were allowed to cool, and their individual masses were recorded. The mass loss from each of the samples showed the amounts of ignitable materials on the sands. **Eq. (3)** was used to evaluate the LOI.

$$\Delta m_{LOI} = \frac{(m_s + m_f)}{m_s} \; x\, 100 \quad (3)$$

where, Δm_{LOI} represents the loss on ignition (%); m_s is the mass of the sand before firing (g); m_f is the mass of the sand after firing (g).

Hardness. Mohs hardness scale was used to evaluate for the relative resistance of the quartz and topaz sands. This was done by scratching the sands against other substances of known hardness on the Mohs hardness scale. In this case, there are twelve (10) minerals in the test kit with each number standing for a hardness value. The mineral that could not be scratched by quartz and topaz sands is said to have the same hardness value as the sands. On the Mohs scale, Talc has a hardness value of 1, Gypsum 2, Calcite 3, Fluorite 4, Apatite 5, Orthoclase 6, Quartz 7, Topaz 8, Corundum 9, and Diamond 10 in an order of increasing hardness value.

Resin-Coated Sand (RCS). A resin-coated proppant was produced from the Diglycidyl ether of bisphenol-A (DGEBA) E-51 epoxy resin and an epoxy hardener using a simple method adopted from US4460717A and EP1757382A1 patents. The procedures used for the modification of the sand involved the following methods: the sand was washed and allowed to dry. The epoxy resin and hardener were measured and mixed in the ratio 3:1 respectively using a measuring cup. The mixture was stirred vigorously using wooden sticks, a dropper was used to drop the mixture on the sand. The slurry of the sand and epoxy resin was then mixed to ensure the epoxy encapsulates the whole of the sand. When the epoxy resin and sand mixture was about to set, the individual grain with the resin coating were transferred to a plane surface and allowed to cure for 48 hours at room temperature of 29°C.

Results and Discussion

Figures 3 and **4** showed the results of the X-ray fluorescence test (XRF) of the characterization of the quartz and topaz sands. The results showed that quartz sand contained 79.93% of silicon oxide (sio_2). It also contained Aluminium oxide (Al_2o_3) of 2.021% and magnesium oxide (MgO) of 0.53%. Similarly, topaz sand contained 72.81%, Aluminium oxide of 1.453% and MgO of 0.86%. These elements are the major constituent in the sands. The results showed that the sand was majorly composed of silicon oxide (sio_2). Liang et al. (2016) reported that sand that have high silica content are best candidate as proppant in hydraulic fracturing operation and have economic advantages. The work of Hu et al. (2014) and Curimbaba and Kerr De Paiva Cortes (2011) all reported that good proppant should contain up to 70% of silicon oxide to be suitable for use in hydraulic fracturing operations. The proposed proppant gave a higher value of the recommended proppant as suggested from the literature. It is also interesting to note that quartz and topaz sands used in this study meet the required standard based on the API and ISO recommended standard.

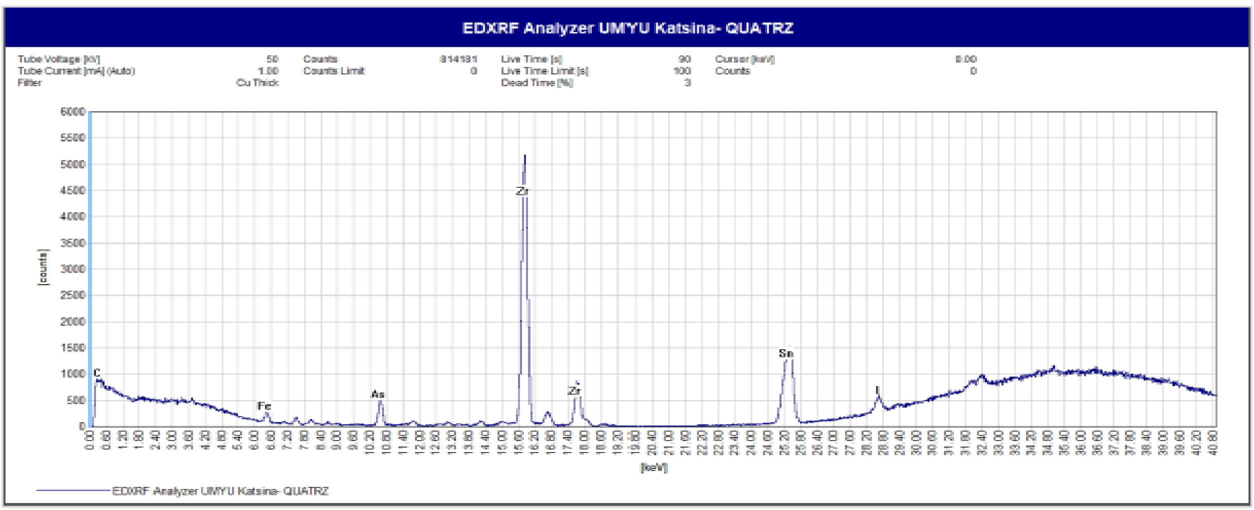

Figure 3—XRF result for Quartz sand.

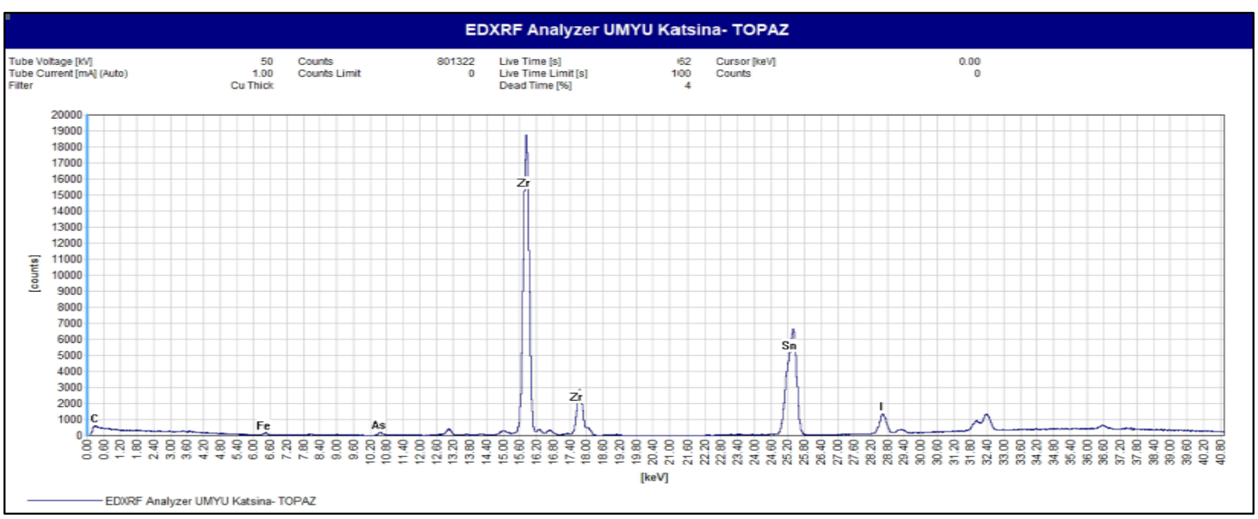

Figure 4—XRF result for Topaz sand.

Sieve Test Result. Table 1 showed the results of the sand sieving test for quartz sand. The sieve sizes range from 1.18-0.300 (mm). It can be observed that sieve size reduces as sample weight increases until reached at mesh size of 40 mm. The percentage retained increases at each mesh size sample, percentage passing of the sand at 100% reduces at each sand passing.

Table 1—Sand Sieve Test for Quartz sand.

Sieve Number	Sieve size (mm)	Mass retained (S_w) (g)	Retained on sieve $(S_w \times 100)/T_{DS}$	Passing (%)	Cumulative retained (%)
16	1.18	0.00	0.00	100	0.00
20	0.850	54.71	2.43	97.57	2.43
25	0.710	279.48	12.42	85.15	14.85
30	0.600	854.92	37.97	47.18	52.82
35	0.500	949.28	42.19	5.00	95.01
40	0.425	111.56	4.96	0.00	100
Pan		0.00	0.00	0.00	0.00

Note: Total dry sand (T_{DS}) = 2250 g

Table 2 showed similar behavior for the topaz sand. Sample weight increases as percentage retained increases. The results of the sieve test showed that the sand is evenly distributed. In addition, the different mesh size of the sand was used to determine the mass retained and the percentage retained of the sand to obtain the particle size distribution of the sand. The cumulative percentage of the sand was retained at 100%.

Table 2—Sand Sieve Test for Topaz sand.

Sieve Number	Sieve size (mm)	Mass retained (S_w)(g)	Retained on sieve $(S_w \times 100)/T_{DS}$	Passing (%)	Cumulative retained (%)
16	1.18	0.00	0.00	100	0.00
20	0.86	56	2.47	97.53	2.47
25	0.71	281.91	12.47	85.06	14.94
30	0.60	862.34	38.12	46.94	53.06
35	0.551	951.83	42.09	4.85	95.15
40	0.43	110.00	4.87	0.00	100
Pan		0.00	0.00	0.00	0.00

*Note:Total dry sand (T_{DS}) of Topaz = 2262 g

Figures 5 and **6** depict the particle size distribution curves for quartz and topaz sands. Both sands exhibit a steep portion of the curve between 0.6 mm and 0.85 mm, indicating that most particles fall within this size range. This uniformity aligns with the studies of Heagy et al. (2014), which highlight the importance of well-sorted sands for effective proppant performance in hydraulic fracturing. The flatter regions at the extremes suggest minimal coarse and fine particles, which are desirable for maintaining consistent fracture conductivity as noted by Guo and Tan (2017). Overall, the particle size distribution results suggest that both quartz and topaz sands have potential as proppants which is in consonance with the findings of Zhang et al. (2020), who identified mediumsized proppants as optimal for fracture stability and hydrocarbon flow. Further testing of other properties, such as crush resistance, is necessary to confirm their suitability, as emphasized by Duchnowska et al. (2023).

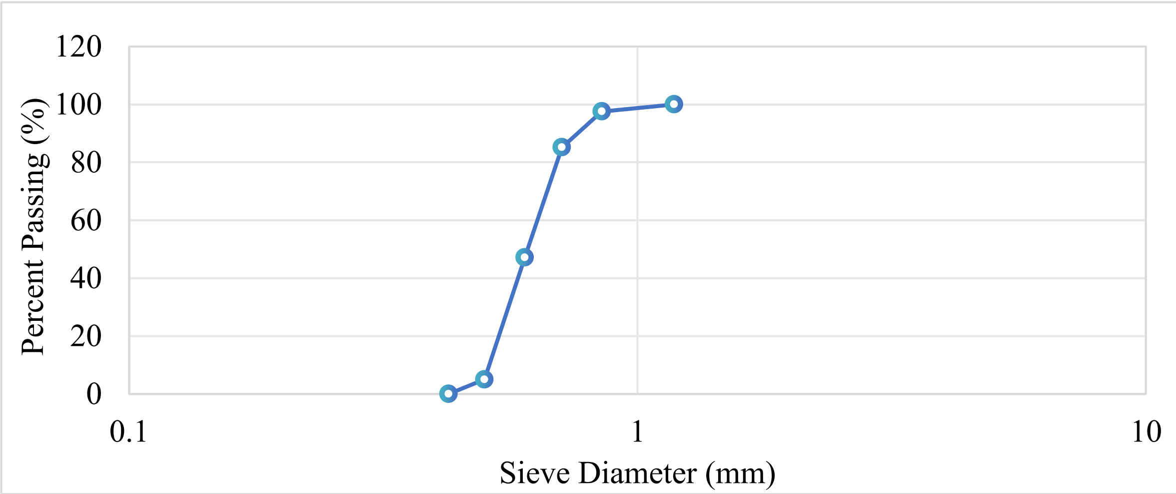

Figure 5—Percent passing (%) against sieve Diameter (mm) for Quartz sand.

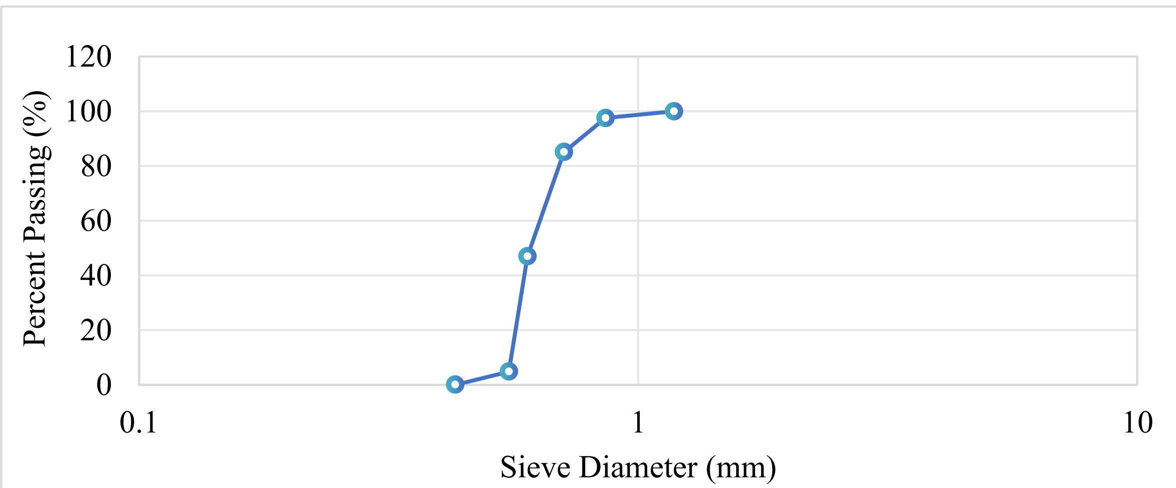

Figure 6—Percentage passing (%) against sieve size (mm) for Topaz sand.

Sphericity and Roundness Test Result. Tables 3 and **4** present the results of the quartz and topaz sand selected at random for the sphericity and roundness test. The table of the results showed that the quartz sand had sphericity of 0.7 which was obtained by dividing the total sum by the number of samples. Similarly, for the topaz sand, the sphericity was 0.7 also obtained by the average of the total sum of samples divided by the number of samples. The results agree with both ISO 13503-2 and API RP 56, which specify a sphericity of ≥ 0.6. The sphericity results of 0.62 from Kamel et al. (2019) are consistent with the current study. According to API/ISO standards, the recommended best practice is for sand samples to have a sphericity and roundness of ≥ 0.6 to be suitable as proppants. **Table 5** presents the average comparison of quartz and topaz sands, indicating an average roundness of 0.7.

Table 3—Sphericity and Roundness for Quartz sand (20/40 mesh size).

Sample code number	Quartz Sand		Sample code number	Quartz Sand	
	Sphericity	Roundness		Sphericity	Roundness
QS 1	0.9	0.5	QS11	0.8	0.7
QS 2	0.7	0.7	QS12	0.6	0.5
QS 3	0.8	05	QS13	0.5	0.7
QS 4	0.9	0.6	QS14	0.7	0.8
QS 5	0.7	0.9	QS15	0.9	0.9
QS 6	0.9	0.7	QS16	0.5	0.9
QS 7	0.9	0.7	QS17	0.7	0.5
QS 8	0.5	0.9	QS18	0.6	0.6
QS 9	0.6	0.8	QS19	0.6	0.7
QS 10	0.7	0.6	QS20	0.5	0.8

Table 4—Sphericity and Roundness for Topaz sand (20/40 Mesh size).

Sample code number	Topaz Sand		Sample code number	Topaz Sand	
	Sphericity	Roundness		Sphericity	Roundness
TS 1	0.9	0.7	TS11	0.6	0.8
TS 2	0.8	0.8	TS12	0.5	0.7
TS 3	0.8	0.6	TS13	0.8	0.7
TS 4	0.9	0.6	TS14	0.6	0.8
TS 5	0.7	0.7	TS15	0.7	0.8
TS 6	0.6	0.8	TS16	0.7	0.6
TS 7	0.5	0.5	TS17	0.5	0.8
TS 8	0.9	0.8	TS18	0.9	0.7
TS 9	0.7	0.7	TS19	0.8	0.6
TS 10	0.6	0.7	TS20	0.5	0.6

Table 5—Average sphericity and roundness for Quartz and Topaz sand.

Parameters	Quartz sand	Topaz sand
Sphericity	0.7	0.7
Roundness	0.7	0.7

Turbidity Result. Table 6 shows that the turbidity for quartz sand was 2.8 NTU, while for topaz sand was 3.83 NTU. Although Liang et al. (2016) reported a slightly higher turbidity value of 7.45 NTU, which exceeds the values found in the present work, all results meet the accepted limit set by API RP 56 and ISO 13503-2 (<250 NTU). Both quartz and topaz sand recorded a small number of suspended particles making them suitable for use as proppants.

Table 6—Turbidity of Quartz and Topaz sand.

Sample	Turbidity (NTU)	Sample	Turbidity (NTU)
Distilled water	0.42	Distilled water	0.42
Distilled water + Quartz sand	3.22	Distilled water + Topaz sand	4.25
Quartz sand	2.80	Topaz sand	3.83

Bulk Density Result. Table 7 presents the bulk density results, which are $1.24\ (\frac{g}{cm^3})$ and $1.28\ \left(\frac{g}{cm^3}\right)$ for the two sands. These results indicate that both sands comply with the ISO $13503-2$ standard, which requires a bulk density of less than $2.0\ \left(\frac{g}{cm^3}\right)$. Moreover, the work of Zwalatha et al. (2024) reported that proppants with high bulk density are not easily transported with fracturing fluids. The proppants could be prone to settle in the wellbore even before reaching into hydraulic fractures. However, the good thing about the quartz sand and topaz sand is the low bulk density value which makes them suitable for hydraulic fracturing operation.

Table 7—Bulk density result.

Sample code number	Bulk Mass (g)	Bulk Volume (cm3)	Bulk Density (g/cm3)
QS	560.96	452.50	1.24
TS	483.51	378.94	1.28

Acid Solubility Result. Table 8 shows the results of the acid solubility test. Quartz sand and Topaz sand recorded solubility percentages of 1.50% and 1.72%, respectively. According to the API RP 19C standard, proppant materials should exhibit acid solubility values of < 2% to be considered suitable for hydraulic fracturing operations. Both Quartz and Topaz sands fall within this acceptable range, demonstrating their potential suitability for use as proppants. The findings in this work align with other studies that have emphasized the importance of low acid solubility for proppant materials. For example, Xu et al. (2022) found that proppants with acid solubility values below 2% maintained structural integrity under reservoir conditions, thus enhancing the overall efficiency of hydraulic fracturing operations. They also highlighted that proppants with low solubility in acidic environments are less likely to degrade, ensuring better performance and longer service life in fracturing applications. The slight difference in solubility values between Quartz and Topaz sands may reflect differences in their mineralogical compositions, yet both remain well within industry-accepted standards, supporting their potential applicability as effective proppants in hydraulic fracturing jobs.

Table 8—Acid solubility result.

Samples	Weight before (g)	Weight after (g)	Solubility (%)
Quartz sand	5.00	4.925	1.50
Topaz sand	5.00	4.914	1.72

Crush Resistance Result. Figure 7 displays the percentage of crushed material at varying stress levels for the uncoated sand samples. At 1000 psi the percentage of fines generated for quartz is 4.65% while for topaz is 4.12%. After increasing the pressure to 2000 psi, the percentage of fines increases to 7.73% for quartz and 7.24% for topaz sand. The maximum closure stress level was reached at 3000 psi with a percentage of fines generated to be 10.89% for quartz sand and 10.33% for topaz sand. Based on API RP 56, frac sand should generate <10% fines at a given closure stress level to be suitable for use at that stress level. The test results show that the strength of the uncoated sands varies from 1000 psi - 3000 psi. However, for wells with closure stress greater than 3000 psi, the quartz and topaz sands will not be used at such pressures and will generate fines (> 10%), hence, there is need to coat the sand to improve its strength.

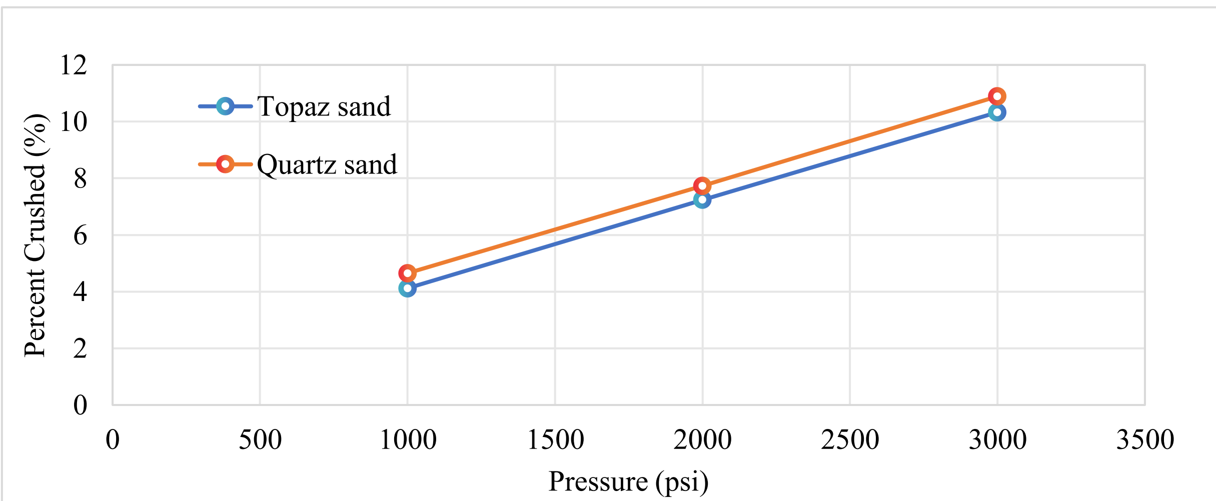

Figure 7— Crush resistance result for 20/40 mesh size Quartz and Topaz sand (Uncoated sand).

Figure 8 clearly indicates that the epoxy coating significantly enhanced the crush resistance of both topaz and quartz sands. The test results show that the strength of the sand varies from 1000 psi - 4000 psi. Both resin-coated quartz sand and topaz sand can withstand crush resistance at closure stress level of up to 4000 psi. At lower closure stress levels such as between 2000 psi to 3000 psi, the percentage of crushed material was significantly reduced in the coated samples compared to the uncoated ones. Moreover, the coated samples maintained much lower crushing percentages as seen in Figure 8 with a value of 7.51% and 7.10% at 3000 psi for quartz and topaz sand respectively. This indicates that the coating effectively protected the sand grains from breaking down under higher stress level. The result is in line with the work of Zoveidavianpoor and Gharibi (2015) who found that proppants with polymer coatings exhibited enhanced resistance to crushing particularly at higher stress levels.

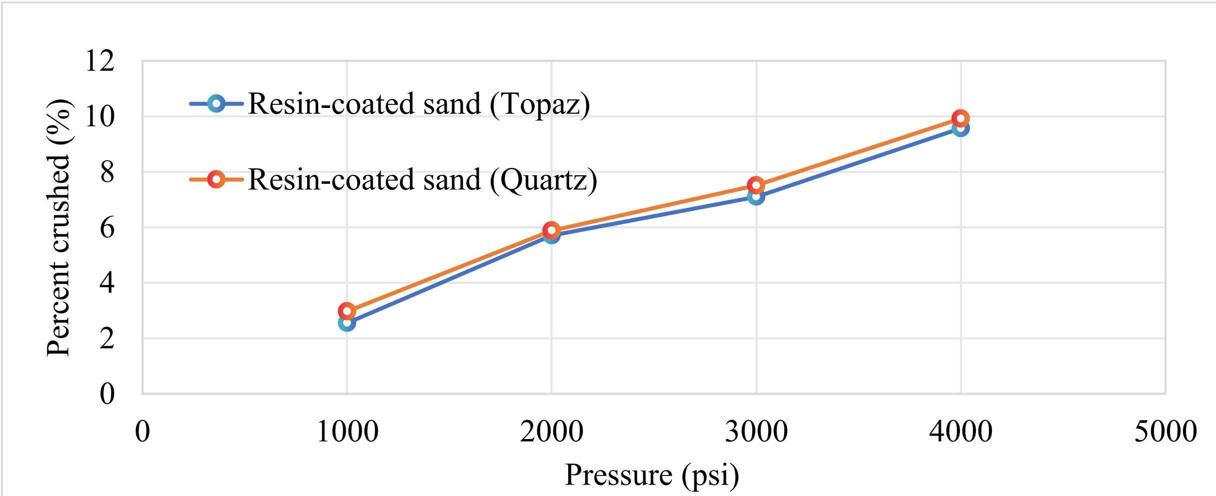

Figure 8— Crush resistance result for resin-coated Quartz and Topaz sand.

Loss on ignition (LOI) Result. Table 9 is the results of loss on ignition which showed that before heating the sample at 900ºC, it was twelve grams for both quartz and topaz samples. However, after subjecting the sands to heat, the values obtained were 11.80 and 11.83 grams for quartz and topaz sand respectively. This indicates that both quartz and topaz sands have low loss on ignition values, with quartz sand showing a 1.67% loss and topaz sand a 1.42% loss. This result aligns with studies by Haque et al. (2019), who reported that proppants with LOI values below 2% are considered suitable for hydraulic fracturing applications, as they have minimal impurities that could affect performance. According to the API RP 19C, lower LOI values are desirable in proppants as they correlate with better thermal stability and reduced risk of chemical reactions during hydraulic fracturing operations.

Table 9—Loss on Ignition for Quartz and Topaz sand.

@ 900°C	Quartz sand	Topaz sand
Mass before heating (g)	12	12
Mass after heating (g)	11.80	11.83
Loss on ignition (%)	1.67	1.42

Hardness Result. The hardness was observed to be seven for quartz sand and eight for topaz sand, as shown in **Table 10**. This means that the quartz sand sample can scratch minerals with Mohs hardness values from 1 to 6 but cannot scratch those rated above 7. Similarly, the topaz sand can scratch minerals rated from 1 to 7 on the Mohs scale but not those rated eight or higher.

Table 10—Hardness test for Quartz and Topaz sand.

Minerals	Number	Quartz	Topaz
Talc	1	Scratched	Scratched
Gypsum	2	-	-
Calcite	3	-	-
Fluorite	4	-	-
Apatite	5	-	-
Orthoclase	6	-	-
Quartz	7	7	-
Topaz	8	Not scratched	8
Corundum	9	-	Not scratched
Diamond	10	-	-

Note: The hardness of the quartz and topaz are 7 and 8 respectively.

Table 11 presents a comparison of the results for quartz sand, topaz sand, and the API and ISO standards. The XRF values were 79% for quartz sand and 72% for topaz sand, while Ottawa sand recorded a higher value of 82% which is likely attributed to its formation. The bulk density was 1.24 g/cm^3 for quartz sand and 1.28 g/cm^3 for topaz sand, compared to 1.53 g/cm^3 for Ottawa sand. The crush resistance and loss on ignition values are consistent with the findings of Kamel et al. (2019). Overall, the results meet the required specifications.

Table 11—Comparison of results with standard method.

Properties	Ottawa sand	This study	API/ISO Standard
XRF (silicon oxide)	Ottawa sand	79% for quartz sand; 72% for topaz;	≥ 70 %
Particle sand size	82%	100% for quartz and topaz sand;	> 90 % (850-425μm)
Roundness and sphericity	0.80	0.7 for both quartz and topaz sand;	≥ 0.6
Turbidity	10.0 NTU	2.80 NTU for quartz; 3.83 NTU for topaz;	< 250 NTU
Bulk density	1.53 (g/cm3)	1.24 (g/cm3) for quarts; 1.28 (g/cm3) for topaz sand;	< 2.0 (g/cm3)
Acid solubility	1.00	1.50 % for quartz; 1.72% for topaz;	< 2.0 %
Crush resistance	9.5%	< 10% fines generated @ 2500 psi for quartz and topaz sand (uncoated sand); < 10% fines generated @ 4000 psi for quartz and topaz sand (resin coated sand)	< 10 % fines
Loss on Ignition	2.5%	1.67 % for quartz sand; 1.42% for topaz sand;	< 2.0%

Economic Analysis. The economy analysis was used to investigate the potential of the proppant in hydraulic operations, and to examine the feasibility of the proppants for use in the Niger Delta oil fields. **Tables 12** and **13** show the parameters used for economic analysis.

Table 12—Parameters used for the economic analysis (Capital expenditure).

S/no	Parameters	Quality/price
1	Quartz sand	$ 570 per ton
2	Topaz sand	$ 680 per ton
Total CAPEX		$1250

Table 13—Operating expenses (OPEX).

Parameters	Case A (Topaz sand)	Case B (Quartz sand)
Transportation cost	$400 per ton	$ 300 per ton
Labor assumed two workers	$200	$200
Maintenance/repair expenses	$500	$500
Miscellaneous expenses	$300	$300
Total OPEX	$1400	$1300

The following assumptions were made.

i. Discount rate of 10%,
ii. Each ton of sand generates $2,000 in revenue,
iii. The operation uses 1 ton of sand per year, iv. Project duration will last for ten years.

The following equations were used in the economic analysis.

$$Net\ cash\ flow\ (FV) = Revenue - Total\ OPEX \quad (4)$$

$$PV = \frac{FV}{(1+i)^n} \quad (5)$$

$$NPV = Total\ PV - Initial\ CAPEX \quad (6)$$

where FV is the future value (cash flow per year), $; PV is the present value , $; i is the discount rate, %; n is the number of years.

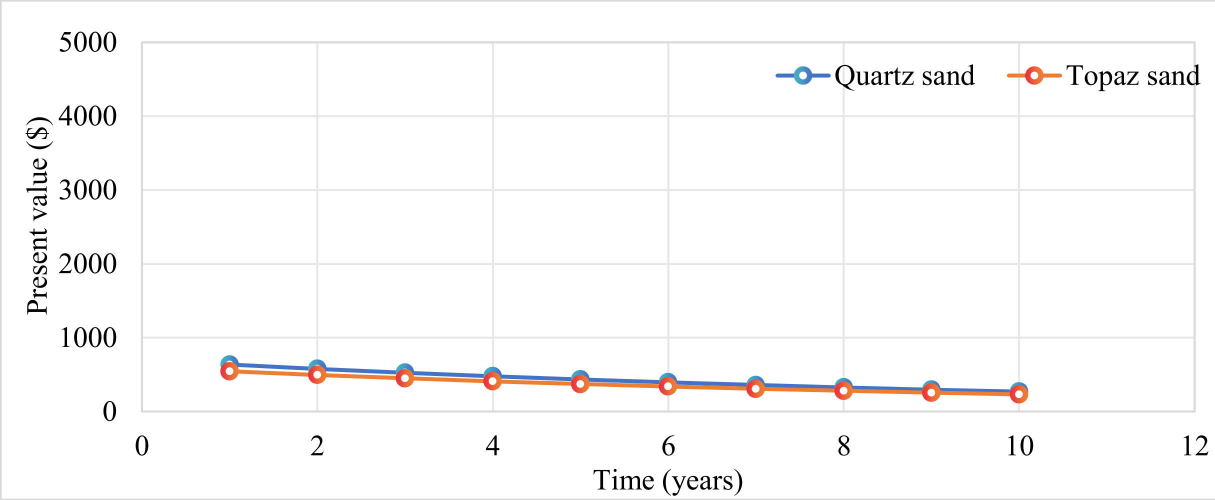

Figure 9—PV of Cash Flows Over Time for Topaz and Quartz Sand.

Figure 9 provides valuable insights into the profitability of using quartz and topaz sand as proppants in Niger Delta oil field. For the project utilizing topaz sand, the PV starts at $545.45 in the first year. Over the course of 10 years, it gradually decreased due to the discounting effect of 10%, reaching $231.32 in the 10th year. The total PV of net cash flows accumulated over the period is $3,686.71. This positive PV indicates that using topaz sand is economically viable and should generate a profitable return over its duration. Similarly, using quartz sand also demonstrates profitability over the 10-year period. It starts with a present value of $636.36 in the first year and shows a consistent decline because of the time value of money. By the 10th year, the value became $270.99. The cumulative PV over the entire project duration amounts to $4,301.60. This indicates that the project will yield a profitable return, confirming its economic viability. These values reflect the fact that the net cash flows generated by each project is sufficient to cover initial investments and still produce a positive return. This supports the conclusion that both projects are economically feasible and will likely contribute positively to the financial goals of the hydraulic fracturing operations in Niger Delta.

Figure 10 shows the comparison of NPV for quartz and topaz sand projects. The higher NPV for quartz sand is attributed to its lower initial capital expenditure and slightly reduced operating expenses compared to topaz sand. This result clearly shows the superior financial performance of quartz sand over topaz.

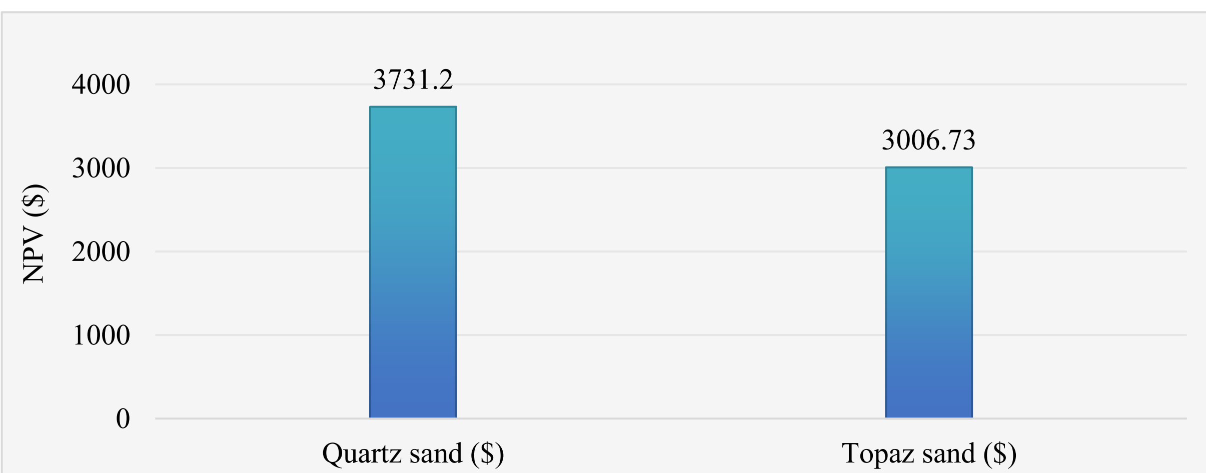

Figure 10—Comparison of Net Present Value (NPV) for Quartz and Topaz Sand.

Conclusions

This research study investigated the use of quartz sand, topaz sand and resin coated sand based on the physical, chemical, and mechanical properties and compared them with the standards outlined in API RP/ISO 13503-2. The study evaluated the performance of the sands as proppants. Quartz sand and topaz sand exhibited excellent quality based on the parameters considered for commercial proppants. High silicon content makes sand the top choice for natural sand proppant. These sands are abundant at mining sites and very affordable. Using quartz sand and topaz sand as proppants can reduce the costs associated with using high-priced Ottawa sands in hydraulic fracturing operations. The following conclusions can be drawn from the experimental study:

i. The X-ray fluorescence (XRF) test on the sand indicates that quartz sand contains a high percentage of silicon oxide, at 79.93%, while topaz sand contains 72.81%.
ii. The sieve test analysis results showed that both quartz sand and topaz sand are 100% compliant in terms of particle size distribution. The crush resistance test results were 8.67% and 8.90%, respectively.
iii. The roundness and sphericity test results were 0.7 and 0.8 respectively. The turbidity of the sand was observed to be 2.80 NTU and 3.83 NTU, while the bulk density of the quartz and topaz sand was 1.24 and 1.28 $\left(\frac{g}{cm}^3\right)$.
iv. The economic analysis carried out showed that quartz had net presence value of 3731.2 ($) while that of topaz sand had 3006.73 ($) respectively. The results indicate that the quartz and topaz sands were profitable for use in hydraulic fracturing operations.
v. The results of the study also showed that the quartz and topaz sands meet the recommended International Standard Organization and American Petroleum Institute methods and thus, a good candidate for use in hydraulic fracturing operations.

Recommendations

The following are the recommendations from the study.

i. Quartz and topaz sand are recommended for use as proppants in hydraulic fracturing operations.
ii. A conductivity test should be conducted to determine the amount of flow that the sand will allow and to assess the influence of the sand on the crush resistance potential of the reservoir.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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