

Utilization of Kazakhstan Sand for Use as Hydraulic Fracturing Proppant

by

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ABSTRACT

Hydraulic fracturing is a widely used well stimulation method to enhance hydrocarbon production from low-permeability reservoirs. Proppants play a critical role in maintaining fracture conductivity by preventing fracture closure under reservoir stress. In Kazakhstan, most of proppants are currently imported, leading to high operational costs and supply chain vulnerabilities. This study investigates the technical feasibility of utilizing locally available Kazakhstan sands as alternative proppant materials.

Eight samples were analyzed: four natural sandstone samples from the Karaganda region (collected at depths of 0.3 m, 1.0 m, 2.1 m, and 3.3 m above ground level), three industrial silica sands from the Mangystau, Aktobe, and Oral regions (provided by AkvaChem, MetPromEnergo, and AMK-Chem), and one commercial ceramic proppant from Russia used as a benchmark. Characterization followed the American Petroleum Institute recommended practices API RP 56 and API RP 58, including particle size distribution (sieve analysis), grain morphology (scanning electron microscopy with Krumbein sphericity and roundness charts), mineralogical composition (X-ray fluorescence and X-ray diffraction), bulk density, turbidity, and crush resistance under closure stresses from 500 to 3000 psi. Proppant pack permeability was assessed qualitatively using a benchtop permeameter under zero confining stress, with explicit recognition that this method does not conform to API RP 19D standards. Acid solubility tests and geopolymer proppant synthesis were not performed in this study.

The results indicate that all local Kazakhstan sands exhibit high quartz purity (SiO_2 content ranging from 82.96% to 93.27%) and pass the API turbidity limit of <250 NTU. However, significant variability was observed in grain morphology and mechanical strength. Most local samples have angular grains (roundness values of 0.5–0.6) and exceed the API allowable limit of 10% fines at closure stresses above 1500 psi. Sample 3 from the Oral region demonstrated the best local performance, producing 10.65% fines at 3000 psi, which still marginally exceeds the API limit. The commercial ceramic proppant (Sample 8) passed all tested API criteria up to 3000 psi. No local sample met all API RP 56/58 requirements simultaneously.

Recommendations for future work include: (1) API RP 19D conductivity measurements under controlled closure stress and reservoir temperature using Kazakh core samples, (2) acid solubility testing per API RP 56, (3) pilot field trials in shallow wells of the Mangyshlak Basin, and (4) experimental development of geopolymer proppants from regional fly ash.

Keywords: hydraulic fracturing, proppant, Kazakhstan sand, API RP 56, API RP 58, crush resistance, sphericity, roundness, silica sand, formation damage, resin coating, geopolymer, fracture conductivity, closure stress, fines migration.

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1. INTRODUCTION

1.1 Background/Problem Definition

Hydraulic fracturing is a critical technique in enhancing oil and gas production from low-permeability reservoirs. Proppants play a central role in this process by maintaining fracture conductivity after the injection of fracturing fluids, thereby enabling sustained hydrocarbon flow. Conventional proppants, such as sand, ceramic, and sintered bauxite, vary in strength, density, and chemical stability, with selection dependent on reservoir pressure, temperature, and fluid composition. High-strength materials are often necessary for deep or chemically aggressive environments; however, their production involves specialized manufacturing standards that significantly increase costs.

The industry's reliance on imported proppants presents economic and logistical challenges, particularly in regions with abundant but uncharacterized local materials. In Malaysia, for example, despite ample sand deposits, there is no domestic proppant production, and much of the sand remains insufficiently evaluated for hydraulic fracturing applications (Sobri, 2013). Similar conditions exist in Kazakhstan, which possesses significant sandstone resources but lacks comprehensive studies assessing these materials against established technical criteria. Developing locally sourced proppants offers potential cost savings, reduced supply chain dependence, and customization to regional geological conditions.

In this research, the authors pay attention to assessing the samples of Kazakhstan sandstone of various regions, such as Karaganda, Mangystau, Aktobe, and Oral, and comparing them with commercial proppants. The idea is to check whether the local materials can conform to the standards of the industry and be alternatives that are cost-efficient.

The problem addressed in this work is the absence of a systematic evaluation of Kazakhstan's silica sands for use as hydraulic fracturing proppants. While international studies emphasized mineralogy, particle shape, mechanical strength, permeability, and chemical stability as key parameters, regional research has yet to establish whether available sand meets industry standards or could be improved through processing. Furthermore, alternative lightweight materials such as fly ash or volcanic ash geopolymers show promise due to lower density and favorable transport properties in fracturing fluids, potentially complementing or substituting natural sands where performance gaps exist.

Alternative materials such as geopolymers are noted in the literature but are outside the experimental scope of this work.

At the same time, the choice of proppant material has significant consequences on the formation damage mitigation and fracture conductivity retention. The interaction between the proppant and the rock matrix in the relatively soft or unconsolidated sandstone reservoirs that are common in Kazakhstan can also cause proppant embedment. This is caused by the process of closure stress pushing grains towards the fracture face, which may decrease the effective fracture width by up to 50 percent and seriously affect long-term conductivity. The most serious effect of this mechanical interaction is that it leads to the formation of a so-called mechanical induced fracture face skin (FFS), a damage mechanism in which the crushing of either proppant grain or quartz grain of the reservoir produces a lot of fines. These produced fines move and clog pore throats near the fracture, causing a local decrease in permeability that can extend to 90 percent (Reinicke, 2011). This is worsened by stiff proppants like some ceramics that form high tensile stress concentrations at contact points with the rock and cause the premature development of grain failure. The detection of material selection requirements that lead to uniform distribution of stress, like resin coating usage as a deformable layer to augment the contact area, is hence necessary to curb the occurrence of explosive grain failures as well as ensure that the conductive pathway is necessary to sustain production.

1.2 Objectives

The research objectives are therefore:

1. To characterize Kazakhstan's silica sands in terms of grain morphology, size distribution, mineralogy, mechanical strength, permeability, and acid solubility using API RP 19C, API RP 56, and API RP 58 standardized methods.
2. To compare Karaganda, Mangystau, Aktobe, and Oral region sands with internationally used commercial proppants and to evaluate their compliance with API RP 19C, API RP 56 and API RP 58 standards for hydraulic fracturing operations, including comprehensive characterization through particle size distribution (sieve analysis), roundness and sphericity, bulk density, turbidity, X-ray diffraction (mineralogical composition), crush resistance, as well as permeability and conductivity measurements.
3. To analyze the implications of grain morphology (sphericity/roundness) and crush resistance of local sands on potential formation damage mechanisms, such as proppant embedment and fines migration, based on experimental results and literature criteria.

1.3 Scope of Work

The following experimental work has been completed, and is limited to that scope:

- Eight samples were collected and analyzed in the laboratory: four field sandstones of Karaganda (depths of 0.3 m, 1.0 m, 2.1 m, 3.3 m), three industrial silica sands of Mangystau, Aktobe, and Oral (supplied by AkvaChem, MetPromEnergo, AMK-Chem), and one commercial ceramic proppant.
- Characterization, based on API RP 19/56/58: sieve analysis (particle size distribution), SEM imaging (sphericity/roundness, using Krumbein chart), XRF/XRD (mineralogy), bulk density, turbidity, crush resistance (500-3000 psi).
- Comparison of the local samples with the commercial proppant and API limits.
- Proppant pack permeability evaluation at zero confining stress (zero confining stress benchtop permeameter) with a specific mention of non-adherence with API RP 19D.
- Discussion of formation damage potential based on measured grain shape and crush resistance, without experimental embedment tests.

The following were not carried out and are specifically not mentioned: synthesis and testing of geopolymers, API RP 19D conduction during closure stress, acid solubility testing, and long-term conductivity cycles. These can be proposed in the work in the future.

1.4 Thesis structure

This thesis is structured as follows: Chapter 2 reviews existing literature on hydraulic fracturing proppant types and evaluation methodologies; Chapter 3 describes sampling procedures and experimental setups; Chapter 4 presents result from laboratory testing and simulations alongside comparative analysis; Chapter 5 summarizes findings with recommendations for future development of Kazakhstan's proppant resources.

By integrating both technical performance requirements and regional resource considerations, this study aims to support the strategic development of local hydraulic fracturing materials that meet industry standards while promoting cost efficiency and sustainability in Kazakhstan's petroleum sector.

2. LITERATURE REVIEW

2.1 Hydraulic fracturing

Unconventional reserves include coalbed methane (CBM), shale oil/ gas, and tight gas, which are low-permeability reservoirs and must be stimulated to produce hydrocarbons at an economic rate. Hydraulic fracturing is an established procedure with a lengthy history of application in the past 50 years, and continues to be a favored method of fracturing a tight-rock formation. Hydraulic fracturing is aimed at avoiding formation damage, or overcoming low formation permeability, and a long conductive flow channel allowing hydrocarbons to flow in the wellbore with minimal resistance to increase the rate of oil or gas production (Kothamasu et al. 2012). According to a paper written by Choudhary et al. (2012), during a hydraulic fracturing process, a crack in the rock is formed by pumping fluid through the tubing or casing at pressure, that exceeds the fracture pressure of the rock. The fluid injection keeps flowing into the fractured crack, induced to expand the crack, and then pumping sand-filled fluid and forming a sand pack to hold the fracture open is done once the hydraulic pressure is no longer applied. Fracturing fluid, most times, is a viscous fluid capable of transporting the proppant within the fracture. Proppant is chosen so that it can resist the formation closure stress. Common hydraulic fracturing involves the following steps:

- In the prepad stage, a clean (gelled or non-gelled) fluid (without proppant) is pumped by progressively increasing the rate. The bottomhole pressure and the wellhead pressure are constantly measured to identify the breakdown pressure. After observing breakdown pressure, the rate is lowered, resulting in shutdown, and the behavior of the pressure decline curve is examined.
- Minifrac analysis is the analysis of the pressure-decline data where the fluid drains out of the formation. The numerical simulators are meant to investigate pressure-decline behavior, which provides information on the fluid efficiency and the closure pressure. The parameters of the model of fracturing-design are adjusted to reflect the measured pressure of the closure, using the analysis; a couple of modifications can be made to the final job design before pumping. As an illustration, in case fluid efficiency during the experiment is found to be less than expected, then pad volume can be adjusted to produce the fracture geometry required.
- Pad is a linear viscous gel or highly viscous cross-linked fluid that is injected to fragment a fracture and advance the fracture structure. This is a stage that is proppant-free.
- The proppant-laden fluid stage is succeeded by the proppant-laden stage, which is normally referred to as slurry. When proppant gets to the end of the fracture, it begins to form

a pack in the fracture. The objective of the proppant pack is to maintain the fracture open and ensure excellent conductivity of the hydrocarbons to flow without resistance.

- Flush is the last step in fracturing. This step aims to force out all the proppant-containing fluid in the wellbore into the formation. Overflush is not usually a good thing to have, and the amount to be used in this step must be computed to bring the final slurry stage immediately over the top perforation.

The rise in hydraulic fracturing operations on a scale never witnessed before has led to the rise in demand for sand/proppant that enhances the conductivity of hydrocarbons. The supply has been increased by the tremendous demand for quality sand needed in the hydraulic fracturing demand gap (Kothamasu et al. 2012).

2.2 Proppants and Types of Proppants

Propping agents are granular materials categorized into three main classes based on their physical properties and intended stress environments:

White Sand is the most widely used and cheapest type of proppant and is usually employed in reservoirs where the stresses of closure are lower than 6,000 psi. Ottawa and Brady sands are high-quality natural sands and represent almost 90 percent of the world's industrial uses because of their high silica content and mechanical dependability.

Resin Coated Proppant (RCP) is natural sand or ceramic beads that, may be coated with epoxy or phenolic resin to increase crush resistance, deter proppant flowback, and decrease fines migration. The coating of resins prevents the point loading and distributes the stress over a wider surface area, doubling the allowable closure stress to around 8,000 psi. - Provide a picture, where possible/available.

Ceramic Proppants are artificial materials, such as Intermediate Strength Proppants (ISP) and High Strength Proppants (HSP), produced by high-temperature sintering of either alumina or bauxite. Ceramics are designed to fit uniformly in size and have high thermal stability, and are therefore used in deep and high-pressure wells that have pressure of more than 10,000 to 15,000 psi. Figure 2-1 presents a photograph of the sample of 20/40- mesh white sand, resin-coated sand, and ceramic proppant. Proppant choice is a compromise between quality and price. Sands are cheaper than resin-coated sands, and much cheaper than ceramic proppants. Proppant cost makes a large percentage of the total stimulation treatment cost, and therefore, the choice should be made based on productivity improvement and payback.

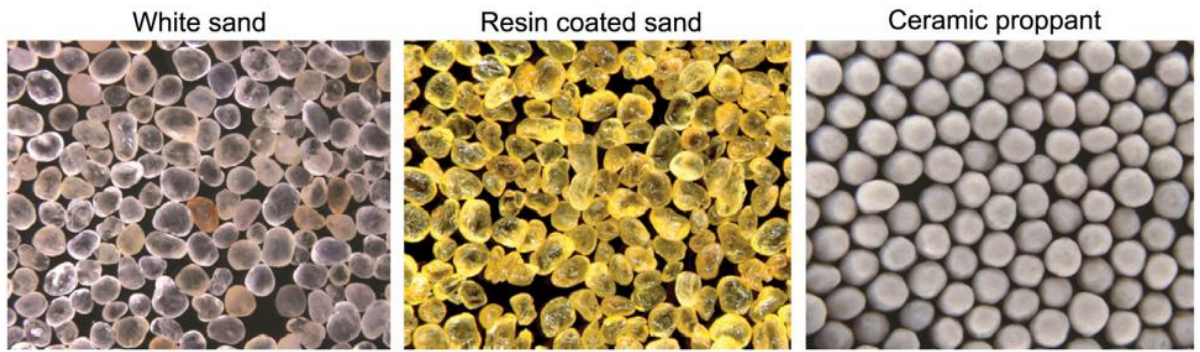


Figure 2-1. Photo of 20/40-mesh proppant types (Smith, 2015)

Innovative materials such as rod-shaped proppants are also being developed to improve pack stability and flowback control, while fly ash-based geopolymers are explored as lightweight, sustainable alternatives for shallower wells.

A detailed overview by Shafiq (2025) points out that the choice of proppant should be based on the geological circumstances, and the performance should be assessed using its compatibility with the reservoir and rheological characteristics. The authors observe that proppants should be able to sustain closure stresses and resist diagenetic changes to maintain fracture conductivity over time.

2.3 Current Market Scenario

The global demand for proppants has surged due to the "Shale Revolution" and the industry-wide shift toward exploiting unconventional resources. Silica sand remains the market leader, comprising approximately 83% of the total proppant market, though ceramic proppants are experiencing the fastest growth segments (Suhaimi, 2013).

In regions like Kazakhstan, there is currently no local proppant manufacturing industry, resulting in a total reliance on imports from the United States, Canada, Russia, and China. This dependency creates economic and logistical vulnerabilities, with stimulation costs sometimes exceeding \$20 million per field development. Consequently, identifying and characterizing local mineral resources is a strategic priority to reduce well stimulation expenses and enhance regional energy independence.

2.4 Characterization of Silica Sands

The standardized testing methods used to characterize natural sands to be used in proppant applications are provided to guarantee consistency and reliability of hydraulic fracturing processes. The proppant evaluation standards have since been consolidated and revised as API RP 56 (Recommended Practice for Testing Sand Used in Hydraulic Fracturing

Operations) and API RP 58 (Recommended Practice for Testing Sand Used This broad standard offers specifications and standard procedures of testing proppants, such as sieve analysis of particle size distribution, median diameter determination, sphericity and roundness testing (usually by means of the Krumbein and Sloss chart), acid solubility analysis, turbidity testing, bulk and absolute density testing, crush resistance testing, and loss on ignition.

One critical parameter is the particle size distribution, where common proppant sizes are between 8 and 140 mesh (0.106 mm -2.360 mm). Common commercial sizes are 16/30, 20/40, 30/50, and 40/70 mesh. Whether to use large or small size fractions directly affects fracture conductivity, where larger proppant sizes tend to maximize early production rates and smaller sizes allow slower long-term production.

Sphericity and roundness, which traditionally are measured by the visual comparative method created by Krumbein and Sloss (1941), have a significant influence on the permeability of the proppant pack. Preferential shape and a limited range of sizes cause increased conductivity, and large differences in particle size and shape cause narrower packing structures to decrease permeability.

Acid solubility testing checks the dissolution in acidic conditions of proppant materials, which is essential since high acid solubility of proppant can result in degradation of proppant in residual fracturing fluids or formation acids, resulting in low fracture conductivity. The API standards outline testing procedures that involve either hydrochloric or formic acid to test the conditions in the downhole.

In the case of silica sand deposits in Kazakhstan, there are few published works on systematic characterization of the silica sand deposits in relation to these API standards. Karaganda is the place where deposits like the Kuu-Chekinskoye have been researched traditionally in the context of construction and not oilfield services. Likewise, Caspian depression sands of the Mangystau region have aeolian sources having good roundness but might have carbonate cements interfering with acid solubility. The Aktobe and Oral (West Kazakhstan) areas have terrigenous deposits that have a varying grain size distribution. These regional sands would be fully characterized in terms of API RP 56 and API RP 58 methodologies, which would provide a baseline of data needed to determine the suitability of these sands as domestic proppant resources.

2.5 Assessment of Lightweight Geopolymer-Based Proppants

Geopolymer proppants have been suggested as an alternative to heavy sands. Haydar and Fakher (2025) found that geopolymers that are formed by fly ash can attain a density of 1.09-1.36 g/cm³, which enhances the transport of proppant in low-viscosity fracturing fluids. Formulations of volcanic ash-based (e.g. B10W30 mix) achieved compressive strengths of about 2,029 psi, which is in the lower range of natural sand proppants.

Nonetheless, a number of constraints exist: compressive strengths are typically less than 5,800 psi needed in deep reservoirs; thermal stability in HPHT conditions is untested; and commercial scalability is not established. De Campos et al. (2019) demonstrated a 2.4% fines at 3,000 psi with metakaolin-based geopolymers with nanocarbon additives after sintering at 130°C, but this processing is costly.

In this thesis, these materials were not experimentally tested. The above review is given in context only. Chapter 6 provides recommendations on future research on Kazakhstani fly ash (available from Karaganda and Ekibastuz power plants).

2.6 Retention Implications of Proppant Properties for Formation

The conductivity of fractures in the long-term is not only determined by the strength of the proppant but also by the relations between proppant grains and the reservoir rock (Bandara et al., 2021). Two damage mechanisms that are induced mechanically can be specifically applied to the current research, namely proppant embedment and fines migration, both of which might result in a phenomenon referred to as mechanically induced fracture face skin (FFS) (Reinicke, 2011).

The process of proppant embedment is driven by closure stress, forcing proppant particles into a soft or unconsolidated fracture face, and effective fracture width decreases. The experimental results of weakly consolidated sandstones indicate that the embedment depth is non-linearly affected by the closure stress and the difference in elastic moduli of the proppant and the formation rock (Zhang et al., 2015; Fan et al., 2022). Extremely, the embedment may reduce the width of the fracture by up to 50 percent, which is highly restrictive in terms of the flow of hydrocarbons (Reinicke, 2011).

The second and potentially more destructive mechanism is fines migration. When the grains of proppant or fragments of reservoir rocks are crushed at the high concentration points, the fine particles are produced (Wang et al., 2025). These fines diffuse to the fracture face and block pore throats, forming a low-permeability, fracture face skin (FFS). Quantitative

measurements have shown that FFS can reduce near-fracture permeability by as much as 90 % compared to undamaged proppant packs (Penny, 2017; Reinicke et al., 2010).

The literature generally identifies three proppant properties that are important to reduce the migration of embedment and fines, and the properties are also the subject of API RP 56 and API RP 58 (API, 1995a; API, 1995b):

- **Sphericity and roundness:** Well-rounded and spherical grains evenly distribute closure stress across larger areas of contact, eliminating local stress concentrations that lead to grain crushing. Krumbein and Sloss (1941) recommend sphericity 0.7 / roundness 0.6 and above. Angular grains (roundness < 0.5) produce loading points, thereby increasing the speed of fines production (Alramahi and Sundberg, 2012).
- **Crush resistance:** The API crush test (≤ 10 % fines at maximum anticipated closure stress) directly quantifies a proppant's tendency to generate fines. Financial fines production is associated with rapid loss of conductivity, particularly when exposed to cyclic stress (Wang et al., 2025; Liang et al., 2020).
- **Particle size uniformity:** The maximum intergranular porosity and minimum retention of the fines in the proppant pack are achieved with a narrow particle size distribution (coefficient of uniformity C_u 1.5 and smaller) (Suhaimi, 2013; Shafiq et al., 2025).

This work measures sphericity, roundness, and crush resistance of Kazakhstan sands (Chapter 4) experimentally. The discussion of these measured properties is related to possible FFS in Chapter 5. In this work, however, no direct embedment tests or API 19D conductivity tests under closure stress were done. Future studies should validate FFS on local sands by using core samples in the reservoirs (Chapter 6).

According to the mechanistic conceptualization of FFS and the established mitigation measures, the combined standards are suggested to choose the proppant in soft and unconsolidated oil wells in Kazakhstan in Table 2-1:

Table 2-1. Proppant Property Specifications for Mitigation of Fracture Face Skin (FFS) (Reinicke, 2011)

Parameter	Recommended Criterion	Basis
Sphericity	≥ 0.7 (Krumbein scale)	Stress distribution, packing efficiency
Roundness	≥ 0.6 (Krumbein scale)	Reduced stress concentrations
Uniformity coefficient ($C_u = D_{40}/D_{90}$)	≤ 1.5	Maximizes porosity, minimizes fines trapping

Resin coating	Recommended for closure stresses >4,000 psi in soft formations	Reduces embedment, controls fines
Crush resistance (API)	$\leq 10\%$ fines at maximum closure stress	Prevents proppant-derived damage
Elastic modulus	$\leq$ formation modulus (for ultra-soft rocks)	Cushioning effect, embedment reduction

3. METHODOLOGY

3.1 Project Flow

Figure 3-1 demonstrates the step-by-step workflow for estimating and developing raw sand from Kazakhstan as a potential proppant, following API RP 56 and API RP 58 standards.

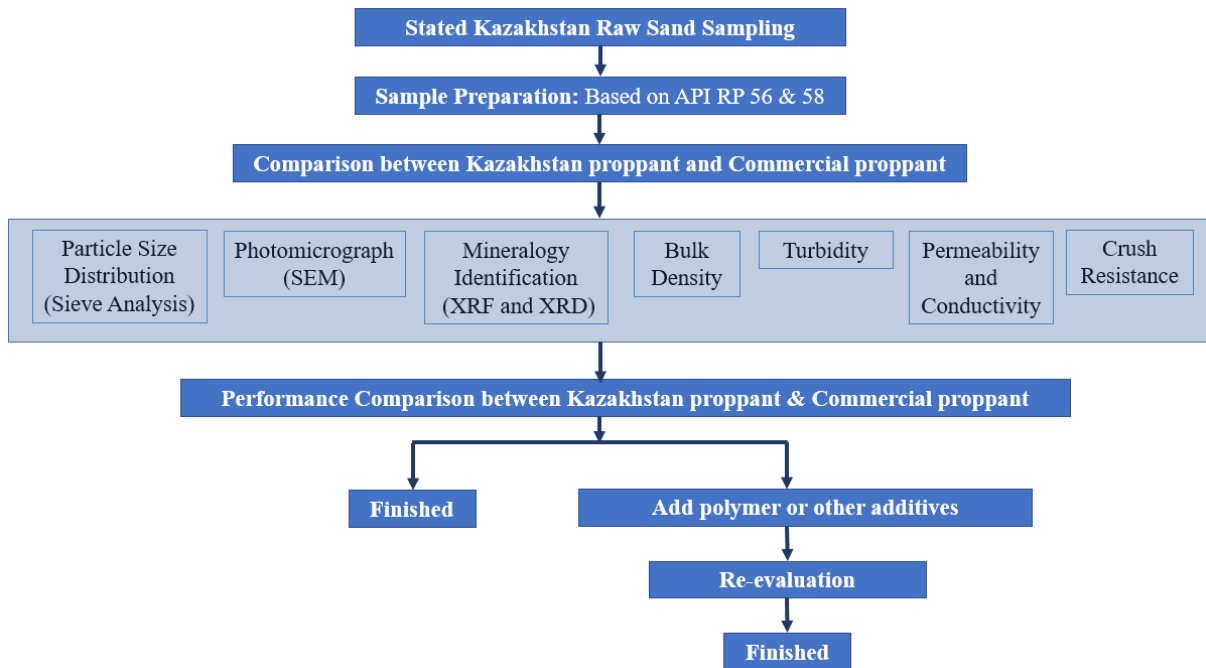


Figure 3-1. Illustration of Project Flow

3.2 Materials

The initial step in the work was the gathering of four samples of local sandstones from a natural outcrop that was found in the Karaganda area. The reason behind this exercise was to acquire raw materials, which were to be analyzed as possible proppants to be used in the hydraulic fracturing process in sandstone reservoirs. Compared with the commercial proppants, which are usually imported and very expensive, the introduction of the domestic sandstones will be a more viable and sustainable option. Thus, the gathering and description of these local supplies is a critical component of the wider research and development project.

Four blocks of sandstone were removed in total, and they were discrete. The sampling site was selected according to accessibility, outcrop exposure quartz-rich composition. Before the collection of the outcrops, the outcrop surface was cleaned to eliminate soil and weathered

fragments. A mixture of geological hammer and chisel was used to remove each sample without causing much breakage or disturbing the structural integrity of the same.

After the extraction, the samples were permanently marked with a marker and covered with polyethylene film to withstand moisture and dust losses during transportation. The sampling location in Table 3-1 was documented with GPS coordinates to enable traceability of the sampling location. On reaching the Nazarbayev University laboratory, the samples were stored in dry and cool conditions awaiting mechanical processing and further characterization.

It was a fieldwork that initiated a methodical study of the possibilities of using Kazakh sandstones as proppant material. It also made it possible to directly compare it with both the regional quartz sandstones and the imported commercial proppants.

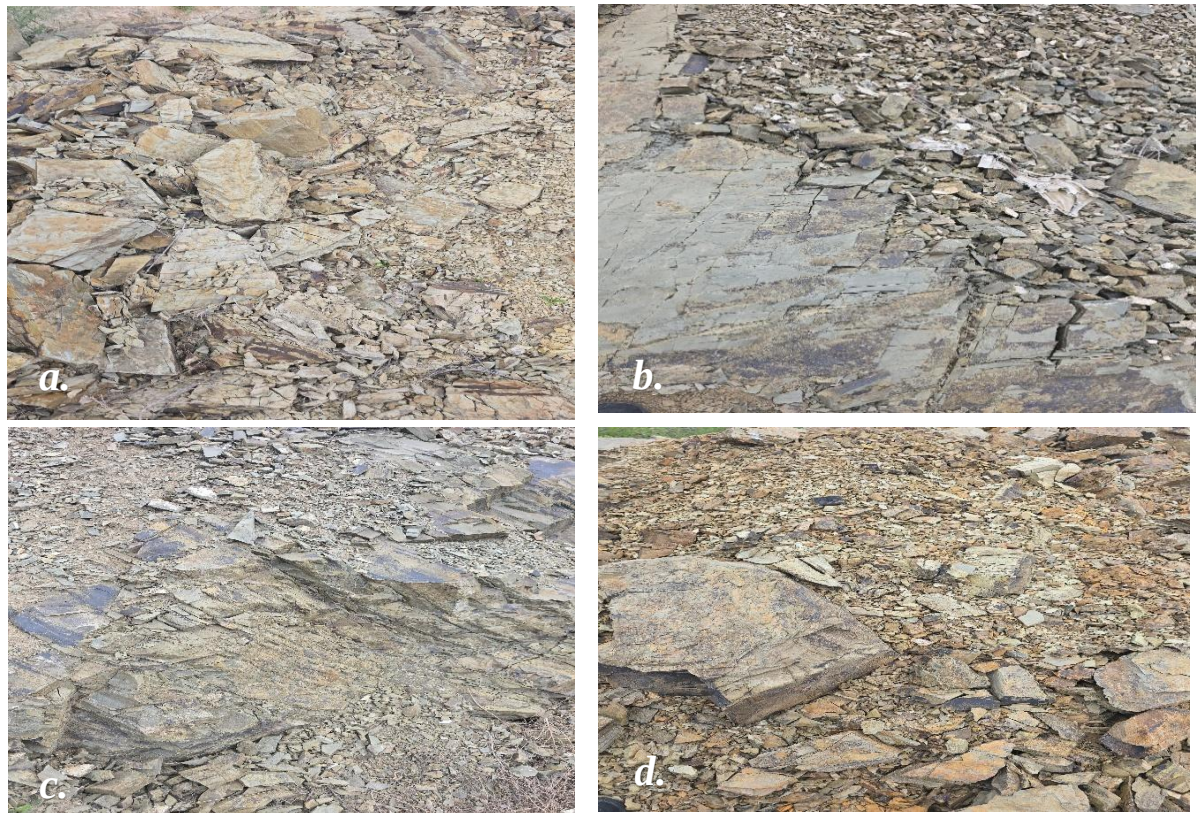


Figure 3-2. Field sampling site near Karaganda showing exposed sandstone outcrop and locations of extracted rock samples (a) corresponds to a depth of 0.3m, (b) to a depth of 1.0m, (c) to a depth of 2.1m, and (d) to a depth of 3.3m above ground level.

Besides the field samples, three silica sandstone samples were furnished by an industrial partner such as “AkvaChem”, "MetPromEnergo", and AMK-Chem. These samples were collected in Mangystau, Aktobe, and Oral regions of Kazakhstan, and they were already in block form, which were to be analyzed. The inclusion of these materials in the study was significant because, first, it enhanced the geological diversity of the data and secondly, it would

facilitate comparison of the characteristics of local field samples with those of other basins in the country.

All the samples were initially observed by the naked eye to determine their texture, size of grains, and overall homogeneity.

Upon labelling, the blocks were put in clean containers with the field samples prepared in advance. Parts of these materials were subsequently ground, heated, and tested according to API RP 56 Standard.



Figure 3-3. Examples of Silica Sand Samples: a) from "AkvaChem" company, Mangystau region, b) from "MetPromEnergo" company, Aktobe region, c) from "AMK-Chem" company, Oral region

This sampling activity guaranteed that the study was more representative in terms of the types of sandstones used, which would subsequently be useful in determining how regional differences in terms of mineralogy and grain shape could influence their possible application as proppant materials.

Three silica sand sandstone samples from the Karaganda region field were also introduced to the experimental group to facilitate an entire comparison of the four samples of the field, as shown in Table 3-1. These were imported to Kazakhstan, and they are commonly used in industrial hydraulic fracturing processes. Their inclusion was useful in setting a standard for determining the quality of local sandstone materials. These indications, henceforth, will be applied to these eight samples:

Table 3-1. Sampling data

#	Description	Location	Depth (m)	Coordinate	Initial Observation
Sample 1	Silica Sand Sandstone from "AkvaChem" company	Mangystau region, Kazakhstan	0,5	43.6423, 51.1671	White in colour, homogeneous
Sample 2	Silica Sand Sandstone from "MetPromEnergo" company	Aktobe region, Kazakhstan	0,3	48.7781, 57.9891	Green in colour, homogeneous
Sample 3	Silica Sand Sandstone from "AMK-Chem" company	Oral region, Kazakhstan	0,5	51.2223, 51.3723	Brown in colour, homogeneous
Sample 4	Sandstone formations occurring at various depths within the field	Karaganda region, Kazakhstan	0,3	53.04352, 69.55250	Grey in colour, heterogeneous
Sample 5	Sandstone formations occurring at various depths within the field	Karaganda region, Kazakhstan	1	54.230684, 68.129386	Grey in colour, heterogeneous
Sample 6	Sandstone formations occurring at various depths within the field	Karaganda region, Kazakhstan	2,1	53.04485, 69.55240	Grey in colour, heterogeneous
Sample 7	Sandstone formations occurring at various depths within the field	Karaganda region, Kazakhstan	3,3	53.050189, 69.55160	Grey in colour, heterogeneous
Sample 8	Commercial proppant	Russian region	not acceptable	not acceptable	Black in colour, homogeneous

3.3 Experiments

Characterization of the sample obtained was carried out in accordance with API RP 56 and 58 standards, including particle size distribution, roundness, and sphericity, bulk density, turbidity, X-ray diffraction, crush resistance, permeability, and conductivity.

3.3.1 Particle Size Distribution

This experiment aims to find out the distribution of the size of the sand particles.

Apparatus/Equipment: Mechanical sieve shaker, drying oven, test sieves of various sizes (1.180 mm, 0.600 mm, 0.425 mm, 0.300 mm, 0.212 mm, 0.150 mm, and 0.063 mm), tray, sieve brush, electronic balances, and scoop.

Procedures:

1. Sample weighted (1kg to an experiment) by heating it in an oven at a temperature of $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$).
2. The number of test sieves was placed on the mechanical shaker as shown in Figure 3-4, in the following sequence, starting with the largest size test sieve suitable to the largest size of material at the bottom of the stack; the smaller size test sieves were formed and a receiver was placed at the bottom of the stack as shown by 7 numbers in Figure 3-4.

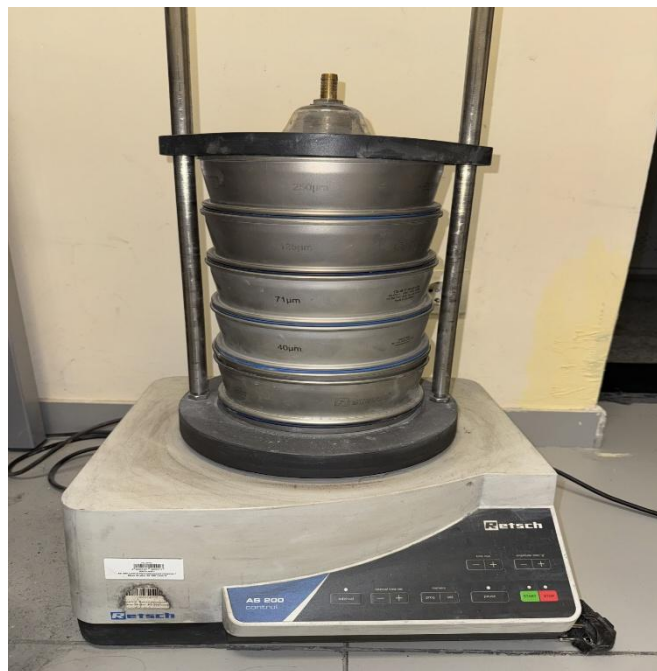


Figure 3-4. Vibro-jet for Sieving and labeled sample containers arranged by size

3. The sample was put on top of the sieve, and the lid is put over the sieve.
4. The test sieves were stirred on the mechanical sieve shaker for 5 minutes.
5. The amounts retained on each of the test sieves are determined.
6. Then the percentages of passing and total percentages of passing were calculated, and a sieve distribution graph was plotted.
7. The samples must be dried in the oven for at least 24 hours to remove all the water that can cause errors during the sieving technique.

In the case of API 56 and API 58, other than 24 larger than the largest sieve size, and other than 1.0 less than the smallest sieve size, 0.1% of the total tested sand sample should not exceed.

3.3.2 Analysis Photomicrograph for Sphericity and Roundness

All hydraulic fracturing is recommended to use round proppant. Roundness is the surface roughness or the sharpness of the corners of the grains. The sphericity, on the other hand, is the shape of the grain or proximity of a sand particle to a sphere. An ideal sphere will be the most spacious in pore space and least resistant to the flow of the hydrocarbons (Gottschling 2005). Figure 3-5 was studied under a Scanning Electron Microscopy (SEM) machine and microscope at 50x and 200x magnification. These were compared with the Krumbein Roundness Sphericity Chart (Figure 3-6) to establish the results. Roundness was entered, and an average roundness and Sphericity obtained. The meaning of 0.6 and above suits API RP 56.



Figure 3-5. Scanning Electron Microscopy

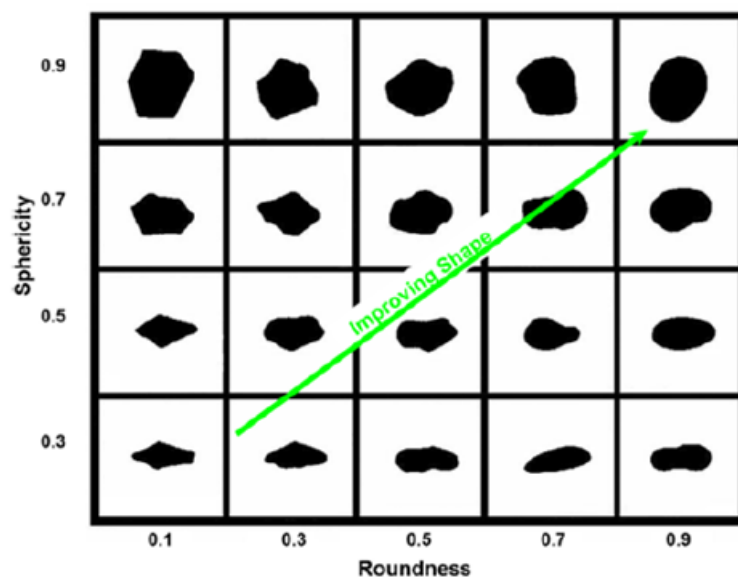


Figure 3-6. Krumbein Roundness and Sphericity Chart (ISO 2006)

Procedures:

1. Clean and dry the sample of sand at 110 °C to remove impurities.
2. Put grains on a stub and observe under SEM at 20 and 40 magnifications.
3. Take 20-30 particles randomly and analyze them.
4. The grains of sand are spherical in shape, determined and round, and have the following by Equation 3.1-3.2:

$$Sphericity = \frac{\text{nominal diameter}}{\text{maximum intercept through the particle}} \quad \text{Equation 3.1}$$

$$Roundness = \frac{\text{Average radius of corners and edges}}{\text{Radius of maximum inscribed circle}} \quad \text{Equation 3.2}$$

5. Compare each grain with the Krumbein chart and assign according to API RP 56 requirements

3.3.3 Mineralogy Analysis

This experiment is to determine the mineralogy of the sand samples.

3.3.3.1 X-Ray Fluorescence Analysis

XRF is used for elemental analysis of many samples. XRF is non-destructive, multi-elemental, fast, and economical if compared to other competitive techniques in Figure 3-7.

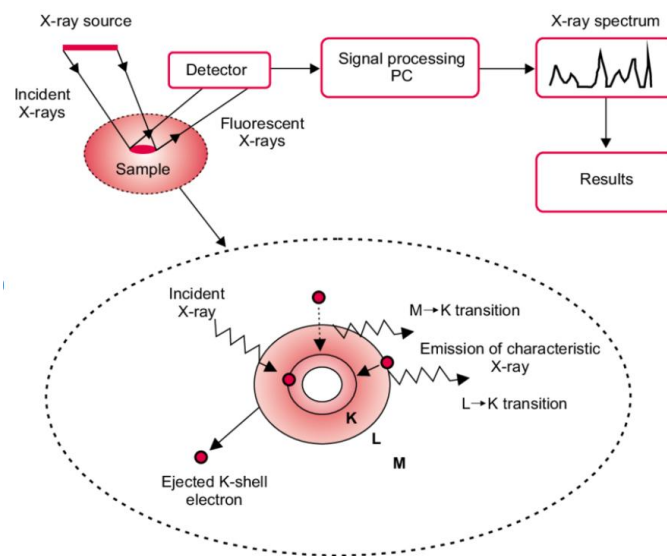


Figure 3-7. Basic Principle of XRF (Haq, 2008)

Procedures:

1. Sample preparation in a solid (or pressed powder) pellet, or fused glass disk.
2. Saturate the sample with high-energy primary X-rays using an X-ray tube.
3. The main X-rays cause the electrons of the inner shells of atoms in the sample to become unstable vacuities.
4. The outer-shell electrons can fall to fill the gaps with secondary (fluorescent) X-rays of energies specific to each element.
5. The emitted X-rays are detected by a detector, and their energy and intensity are recorded.
6. The instrument produces a spectrum (intensity vs. energy). The elements (qualitative) are determined by the peak positions, and the concentrations (quantitative) are determined by the peak intensities.

3.3.3.2 X-Ray Diffraction Analysis

X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material. XRD does not demand huge quantities in the form of powder. The purpose of this experiment is to determine the presence of silica dioxide, SiO_2 in samples.

Equipment/Apparatus: X-ray Powder Diffraction (XRD) and grinder.

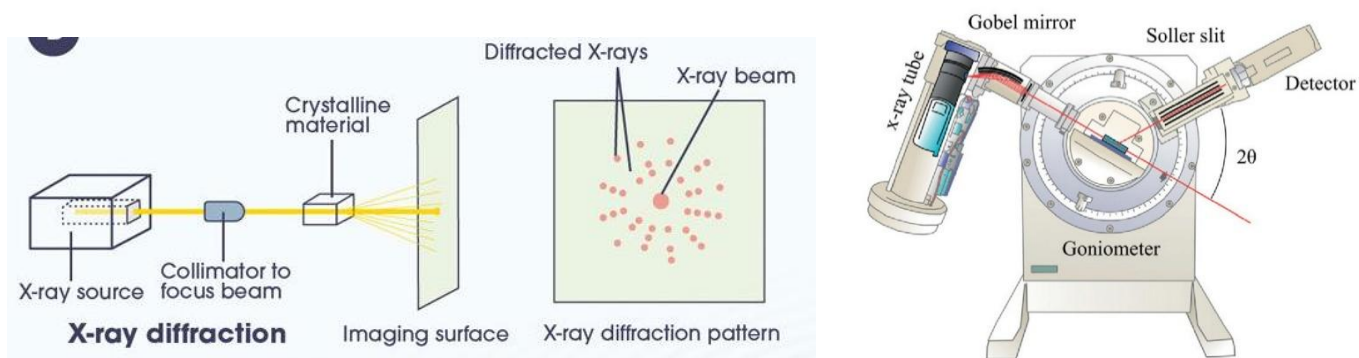


Figure 3-8. Basic Principle of XRD

Procedures:

1. Grind the specimen to fine powder and pour in a flat holder.
2. Insert a placeholder in the goniometer (rotating stage).
3. Beam of direct monochromatic X-rays on the sample.

4. X-rays are scattered by electrons surrounding atoms; the scattered rays are constructively interfering with angles to the Law of Bragg.
5. Diffracted rays are collected by an electronic detector that moves synchronously.
6. Detector records intensity vs. 2θ angle, producing a diffraction pattern with peaks (reflections) unique to the crystalline phase.

3.3.4 Bulk Density Determination

The bulk density of the samples is determined using the graduated cylinder method.

Equipment/Apparatus: Electronic balance and graduated cylinder.

Procedures:

1. Add the sand sample, by additions, each addition being compacted by tapping on the palm.
2. Gently fill to 100 ml and measure the final volume (1 ml = 1 cm³).
3. Weigh the cylinder sand and note.
4. Triple Repeat this three times per sample.
5. The process is continued 3 times with each sample.
6. Average value and bulk density of every sample are determined using Equation 3.3 and Equation 3.4.

$$m_{sand} = m_{cylinder+sand} - m_{empty\ cylinder} \quad \text{Equation 3.3}$$

$$Bulk\ density = \frac{m_{sand}(g)}{V(cc)} \quad \text{Equation 3.4}$$

3.3.5 Turbidity Testing

This procedure is used to establish the occurrence of suspended particles or other fine-divided materials. The turbidity tests were carried out as per API 56 standard.

Equipment/Apparatus: demineralized water, 100 mL conical flask, 20 mL measuring cylinder, pipette, test vial, turbidimeter (calibrated), timer

Procedures:

1. Weigh 20 mL of the sand sample and 100 mL of demineralized water.
2. Add the sand and the water into a conical flask in Figure 3-9.
3. Allow to settle for 30 minutes.
4. Shake with hands vigorously for between 20 and 45 seconds.
5. Allow to settle for 5 minutes.

6. Take the suspension of water-silt at the center with a pipette.
7. Pour the extract into a test vial.
8. Measure turbidity (NTU) with a turbidimeter in Figure 3-10.
9. Check the result of less than 250 NTU by API 56 and API 58 criteria.

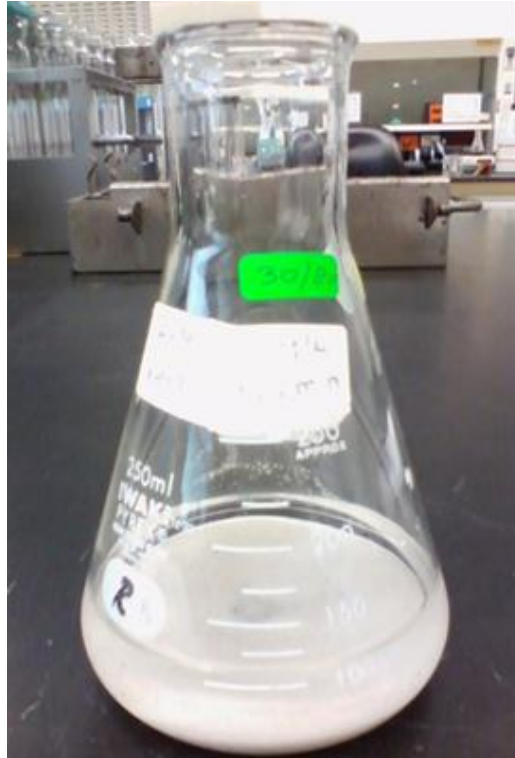


Figure 3-9. Mixture of sand sample and demineralized water in conical flask



Figure 3-10. Turbidimeter

3.3.6 Crush Resistance Determination

This experiment is to determine the crush percentage of the sand samples under specified stress.

Equipment/ Apparatus: Auto Pallet Press machine and automatic balance in Figure 3-11.

Procedures:

1. Sieving of proppant has to be within that range (-20/+40 US mesh sizes).
2. The concentration of crush cell is filled up to 1.95 g/cm².
3. The uniform loading rate is used to achieve the desired stress (500 psi, 1000 psi, 1500 psi, 2000 psi, 2500 psi, 3000 psi).
4. Stress is detained not less than 2 minutes.
5. Material is sieved again as mentioned above.

The amount of crushed material is calculated as the percent weight of proppant smaller than the specified range. API size specifications allow up to 10% of the material outside the given range.



Figure 3-11. Auto Pallet Press Machine

3.3.7 Permeability (Qualitative, Non-API Compliant)

Critical Limitation: API RP 19D is the industry standard of proppant conductivity measurement that involves a servo-controlled press with a constant closure stress on a proppant pack at the temperature and pressure of the reservoir. In the current study, this criterion was not observed.

Rather, water flow through a loose proppant pack under zero confining stress with 30,000ppm brine was measured using a bench-top permeameter (Figure 3-12). The setup lacks:

- Any overburden stress (simulating reservoir overburden) applied.
- Temperature control.
- API-specified cell geometry.

The reported numerical values in Section 4.7 can therefore not be compared with published API conductivity values. They are only given in qualitative internal comparison of a sample in the same zero-stress conditions. These numbers cannot be used to predict field fracture conductivity.

The following is the experimental procedure as recorded originally, but the results should be viewed in the light of the above caveats.

This experiment is to determine the coefficient of permeability and conductivity of sand samples using a permeameter.

Permeability of sand is a value that displays how much sand can allow to flow through liquid, in this case water, to flow through the pore spaces between solid particles. The degree of permeability is calculated by applying a hydraulic pressure gradient in a sample of saturated sand and measuring the consequent flow. Its coefficient of permeability is expressed in terms of velocity. The constant head flow of water in this experiment permeameter is laminar. The quantity of water that went through the sand sample in a known time is measured, and the hydraulic gradient is measured using the manometer tubes.

Equipment/Apparatus: permeameter cell, reservoir tank, manometer set, filter, measuring cylinder, thermometer, and stopwatch.

Procedures:

1. The internal diameter of the permeameter cell is determined in Figure 3-12.



Figure 3-12. Permeameter

2. The air distance between manometer glands along the same line is measured.
3. Sample length is measured and noted.
4. The control valve is closed.
5. The supply valve is opened. Simultaneously, the pinch of the manometer tube cocks is opened one by one to ensure that no air is trapped in the flexible tubing when water is introduced into the manometer tubes.
6. To produce, the permeameter cell is opened at its control valve at the bottom flow. The water levels are measured when the manometer measurements are stable.
7. A measuring cylinder of appropriate capacity is laid under the outlet of the timer, and the discharge reservoir is started.
8. The time is taken when the water has attained the desired height of the measuring cylinder.
9. Measured temperature of the water in the discharge reservoir.
10. A repeat of the experiment is performed 3 times to obtain more accurate results.
11. For this test, a benchtop permeability system is being used, Equations 3-5 and 3-6 to calculate the conductivity of the sand pack, where W_f is the proppant pack width is 2.54 cm, as per the mould that is used to hold the sand in the core holder.

$$kW_f = 5,41 \times 10^{-4} \mu Q / \Delta P \text{ (SI units)} \quad \text{Equation 3-5}$$

$$kW_f = 26,78 \times \mu Q / \Delta P \text{ (US customary units)} \quad \text{Equation 3-6}$$

The value of permeability is computed by the software based on Darcy's Law equation. In this test, 30 000 ppm brine solution is used as the test liquid.

4. RESULTS

4.1 Particle Size Distribution

The mechanical sieve analysis of all eight samples was used to determine the particle size distribution based on API RP 56 procedures. Table 4-1 gives the percentage of sand retained on each size of sieve, in all the samples, to give an idea of the size character of each sample.

Table 4-1. Particle Size Distribution

Sieve Size (mm)	Percentage retained (%)								Recommended API
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	
1,180	0,02	5,72	1,55	0,37	4,01	3,57	0,90	0,06	< 0,1
0,600	0,18	80,77	15,36	9,89	31,96	17,63	57,31	4,11	> 90
0,425	5,36	29,37	66,69	18,27	41,08	67,02	28,39	65,28	
0,300	37,65	12,07	25,86	24,13	31,92	0,31	8,35	27,90	
0,212	49,13	2,23	1,37	20,43	12,12	0,51	1,51	11,98	
0,150	7,27	0,82	6,23	5,41	4,23	0,20	0,20	10,01	
0,063	0,29	0,20	2,53	1,44	2,53	0,05	0,02	0,29	
0,00	0,10	0,11	1,49	0,58	1,31	0,06	0,01	0,23	< 1

As shown in Table 4-1, more than 75% of the sand particles are in the range of 0.3 – 0.6 mm. But most importantly, the results show that the sand is in the range of the desired particle size of 0.41 – 0.60 mm. The sand is not tightly distributed, which means they are not greatly uniform, which could be due to the sampling method.

The cumulative weight should be within 0.5% of the sample weight used in the test. A minimum of 90% of tested sand samples should fall between the designated sieve sizes. According to the API standard, not more than 0.1% of the total tested sand sample should be larger than the first sieve, and not more than 1.0% should be smaller than the last sieve. Details of the individual sieve analysis results for each sample are attached below in Tables 4-2 through 4-9.

Table 4-2. Sieve Analysis Result for Sample 1

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	324,70	0,20	0,02
0,600	401,90	403,40	1,50	0,18
0,425	301,60	346,10	44,50	5,36
0,300	358,10	670,60	312,50	37,65
0,212	271,20	679,00	407,80	49,13
0,150	252,90	313,20	60,30	7,27
0,063	278,30	280,70	2,40	0,29
Pan	392,40	393,20	0,80	0,10
TOTAL			830,00	100,00

Table 4-2 shows that more than 49% of the sand particles (Sample 1, Mangystau) are retained on the 0.212 mm sieve, indicating a dominant fine fraction in the 0.212–0.300 mm range.

Table 4-3. Sieve Analysis Result for Sample 2

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	372,00	47,50	5,72
0,600	401,90	1072,30	670,40	80,77
0,425	301,60	545,40	243,80	29,37
0,300	358,10	458,30	100,20	12,07
0,212	271,20	289,70	18,50	2,23
0,150	252,90	259,70	6,80	0,82
0,063	278,30	280,00	1,70	0,20
Pan	392,40	393,30	0,90	0,11
TOTAL			1089,80	100,00

Table 4-3 shows that more than 80% of the sand particles (Sample 2, Aktobe) are retained on the 0.600 mm sieve, indicating a very coarse-grained distribution dominated by particles in the 0.600–1.180 mm range.

Table 4-4. Sieve Analysis Result for Sample 3

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	337,37	12,87	1,55
0,600	401,90	529,40	127,50	15,36
0,425	301,60	855,10	553,50	66,69
0,300	358,10	572,70	214,60	25,86
0,212	271,20	282,60	11,40	1,37
0,150	252,90	304,60	51,70	6,23
0,063	278,30	299,30	21,00	2,53
Pan	392,40	404,80	12,40	1,49
TOTAL			1004,97	100,00

Table 4-4 shows that nearly 67% of the sand particles (Sample 3, Oral) are retained on the 0.425 mm sieve, with an additional 26% on the 0.300 mm sieve, indicating a well-concentrated distribution in the 0.300–0.600 mm range, which is favorable for proppant applications.

Table 4-5. Sieve Analysis Result for Sample 4

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	327,60	3,10	0,37
0,600	401,90	484,00	82,10	9,89
0,425	301,60	453,20	151,60	18,27
0,300	358,10	558,40	200,30	24,13
0,212	271,20	440,74	169,54	20,43
0,150	252,90	297,80	44,90	5,41
0,063	278,30	290,23	11,93	1,44
Pan	392,40	397,20	4,80	0,58
TOTAL			668,27	100,00

Table 4-5 shows that Sample 4 (Karaganda, 0.3 m) has a relatively distributed particle size profile, with 18–24% retained on each of the 0.425 mm, 0.300 mm, and 0.212 mm sieves, indicating moderate sorting but significant fine content (20% below 0.212 mm).

Table 4-6. Sieve Analysis Result for Sample 5

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	357,80	33,30	4,01
0,600	401,90	667,20	265,30	31,96
0,425	301,60	642,60	341,00	41,08
0,300	358,10	623,00	264,90	31,92
0,212	271,20	371,80	100,60	12,12
0,150	252,90	288,00	35,10	4,23
0,063	278,30	299,30	21,00	2,53
Pan	392,40	403,30	10,90	1,31
TOTAL			1072,10	100,00

Table 4-6 shows that Sample 5 (Karaganda, 1.0 m) has 41% retained on the 0.425 mm sieve and 32% on both the 0.600 mm and 0.300 mm sieves, indicating a bimodal distribution that may reduce pack permeability due to finer particles filling intergranular voids.

Table 4-7. Sieve Analysis Result for Sample 6

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	354,10	29,60	3,57
0,600	401,90	548,20	146,30	17,63
0,425	301,60	857,90	556,30	67,02
0,300	358,10	360,70	2,60	0,31
0,212	271,20	275,40	4,20	0,51
0,150	252,90	254,60	1,70	0,20
0,063	278,30	278,70	0,40	0,05
Pan	392,40	392,90	0,50	0,06
TOTAL			741,60	100,00

Table 4-7 shows that Sample 6 (Karaganda, 2.1 m) is highly concentrated on the 0.425 mm sieve (67%), with only 0.31% retained on the 0.300 mm sieve and negligible fines below 0.212 mm. This indicates excellent sorting within the 0.425 mm size fraction.

Table 4-8. Sieve Analysis Result for Sample 7

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	332,00	7,50	0,90
0,600	401,90	877,60	475,70	57,31
0,425	301,60	537,20	235,60	28,39
0,300	358,10	427,40	69,30	8,35
0,212	271,20	283,70	12,50	1,51
0,150	252,90	254,60	1,70	0,20
0,063	278,30	278,50	0,20	0,02
Pan	392,40	392,50	0,10	0,01
TOTAL			802,60	100,00

Table 4-8 shows that Sample 7 (Karaganda, 3.3 m) is coarser than other Karaganda samples, with 57% retained on the 0.600 mm sieve and 28% on the 0.425 mm sieve, indicating a dominant coarse fraction above 0.425 mm.

Table 4-9. Sieve Analysis Result for Sample 8

Sieve Size (mm)	Weight of Sieve (g)	Weigh Sieve + Retained (g)	Retained (g)	Percentage (%)
1,180	324,50	325,00	0,50	0,06
0,600	401,90	436,00	34,10	4,11
0,425	301,60	843,40	541,80	65,28
0,300	358,10	589,70	231,60	27,90
0,212	271,20	370,60	99,40	11,98
0,150	252,90	336,00	83,10	10,01
0,063	278,30	280,70	2,40	0,29
Pan	392,40	394,27	1,87	0,23
TOTAL			994,77	100,00

Table 4-9 shows that Sample 8 (commercial ceramic proppant) is tightly distributed, with 65% retained on the 0.425 mm sieve and 28% on the 0.300 mm sieve, demonstrating the narrow particle size distribution expected of manufactured proppants per API specifications.

The sieve analysis shows a significant disparity in grain size distribution across the samples. Sample 1 (Mangystau) is concentrated in the finer range (0.212–0.300 mm), while Sample 2 (Aktobe) is much coarser, with over 80% retained on the 0.600 mm sieve. Samples 4–7 (Karaganda) show more heterogeneous distributions across the 0.3–0.6 mm range. Proppant size directly influences fracture conductivity; larger proppants provide higher initial conductivity but are more prone to crushing and plugging by fine particles.

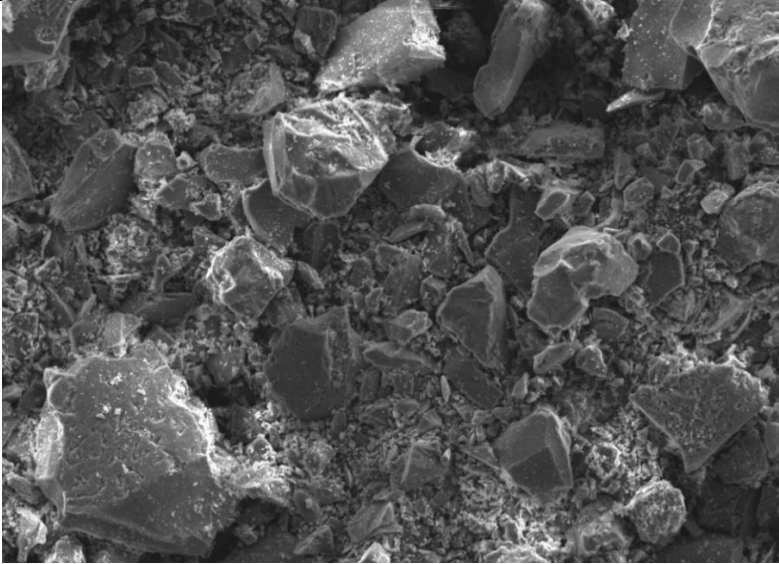
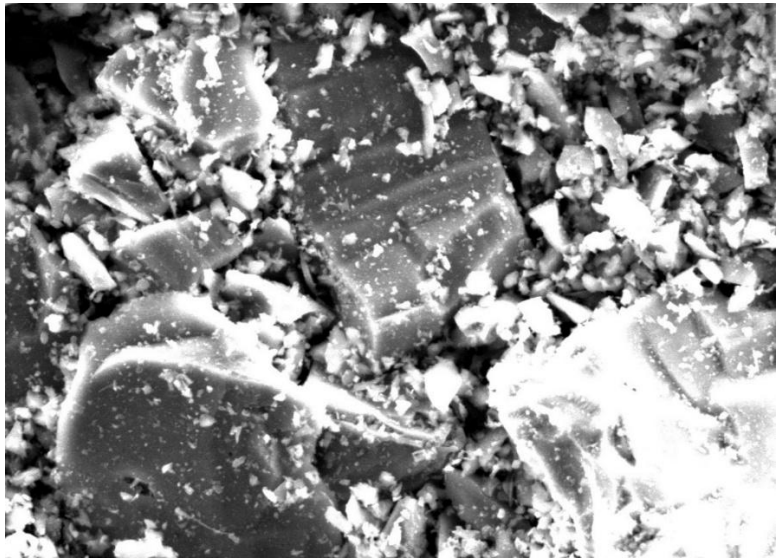
The lack of tight distribution in local samples suggests they are not naturally uniform and would require industrial sorting/sieving to meet API RP 56 standards, which require 90%

of the sample to be within the designated size range. If grain size distribution contains a high percentage of smaller grains, as seen in Sample 1, the proppant-pack permeability will be significantly reduced.

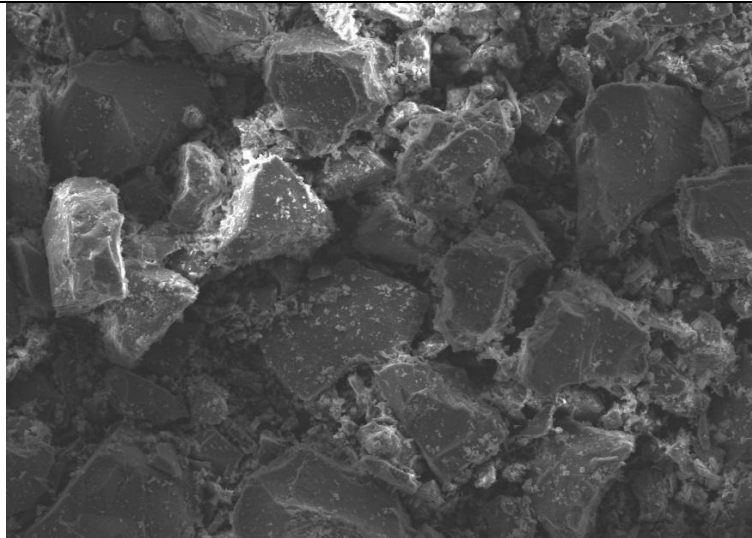
4.2 Photomicrograph for Sphericity and Roundness

The scanning electron microscopy (SEM) was carried out to have a visual observation of the grain morphology of the samples. The photomicrographs have been tabulated in Table 4-10. For accurate comparison, all images of the samples have been presented at a standardized magnification of 200x.

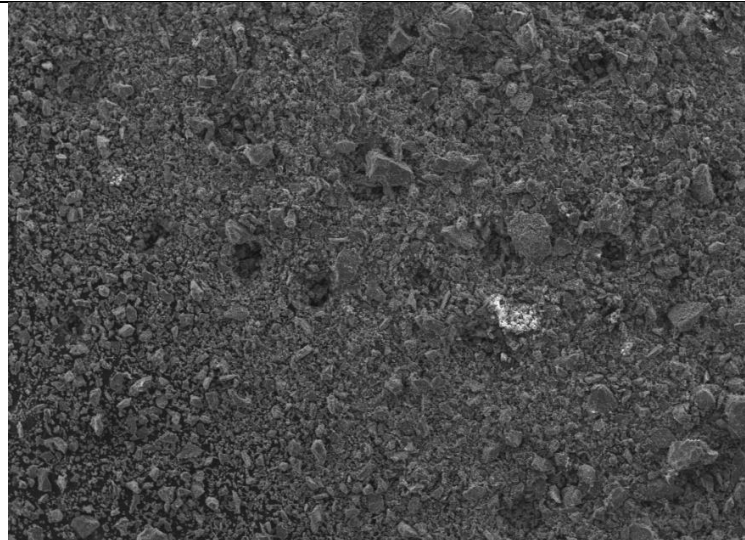
Table 4-10. Photomicrographs

Sample 1 (Mag: 200x)	
	
Sample 2 (Mag: 200x)	
	

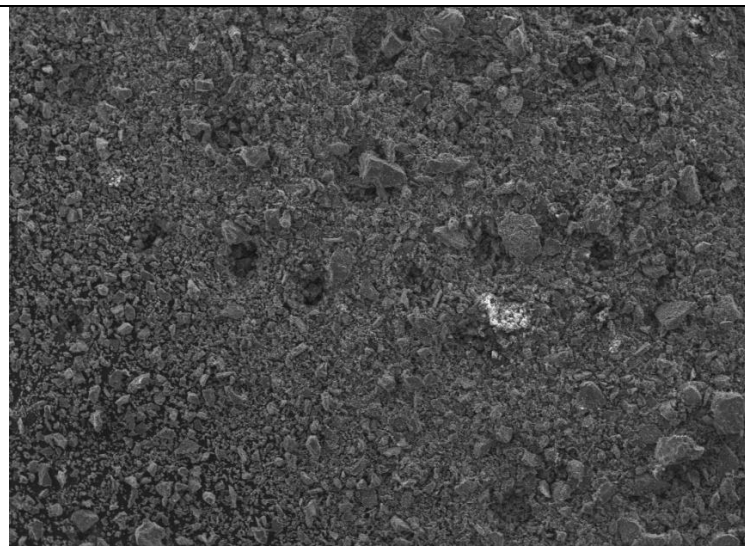
Sample 3 (Mag: 200x)



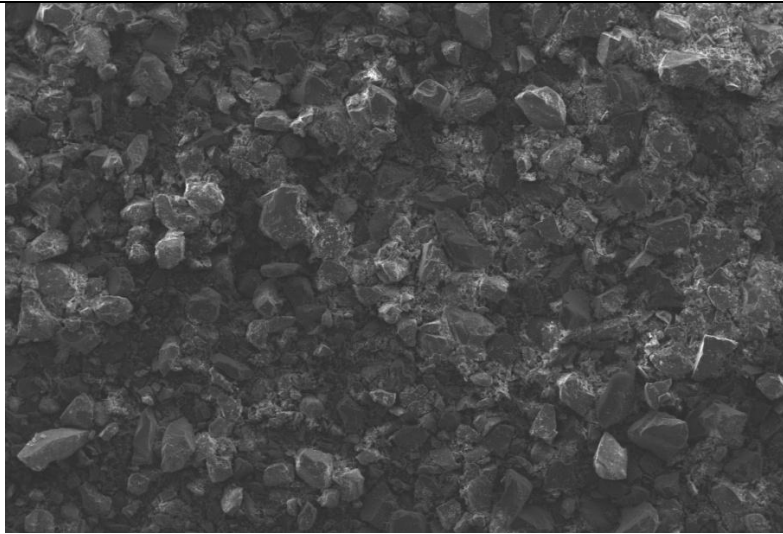
Sample 4 (Mag: 200x)



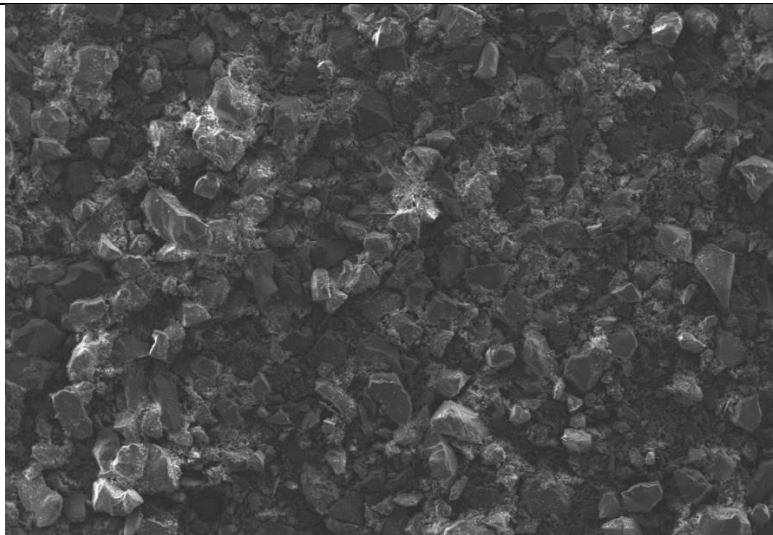
Sample 5 (Mag: 200x)



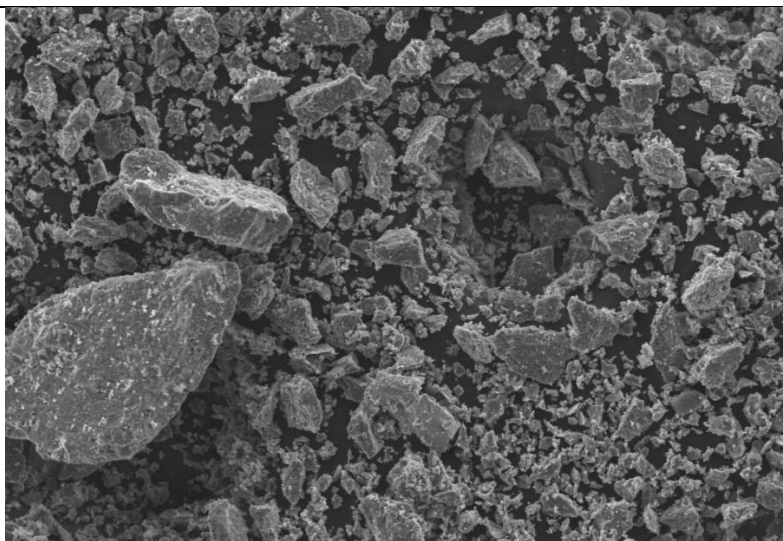
Sample 6 (Mag: 200x)



Sample 7 (Mag: 200x)



Sample 8 (Mag: 200x)



The visual comparison of these photomicrographs with the Krumbein Roundness and Sphericity Chart (Krumbein and Sloss, 1941) was made so as to attribute the values of roundness and sphericity. Table 4-11 summarizes the results of this analysis.

Table 4-11. Roundness and Sphericity Value of Samples

Samples	Roundness	Sphericity
Sample 1	0,6	0,7
Sample 2	0,5	0,7
Sample 3	0,7	0,7
Sample 4	0,6	0,5
Sample 5	0,8	0,5
Sample 6	0,7	0,6
Sample 7	0,5	0,6
Sample 8	0,9	0,9

The commercial Sample 8 exhibits ideal shape characteristics with a 0.9 roundness and 0.9 sphericity. Local Kazakhstan samples range from 0.5 to 0.8 in roundness and 0.5 to 0.7 in sphericity. Specifically, Samples 5 and 6 showed the highest roundness (0.8), while Sample 4 was the most angular (0.5/0.5).

Sphericity affects how the proppant packs, while roundness reduces point loading. The angularity (lower roundness) of local sands is a major limitation; angular grains create more stress concentration, leading to premature grain failure. API RP 56 recommends a mean of 0.6 or higher for both parameters. While some local samples (like Samples 5 and 6) meet this, others fall below the desired threshold, necessitating shape-improvement processes like resin coating.

Roundness and sphericity are critical parameters that influence the porosity of a proppant pack after its placement within the formation. For conventional sand proppants, both properties are typically expected to have values around 0.7, ensuring optimal packing characteristics and fluid flow pathways. As indicated in Table 4-11, Sample 3 satisfies the required roundness criterion and exhibits an ideal sphericity value. In contrast, the locally sourced sand samples fall slightly below the recommended thresholds. Nevertheless, their deviation from the standard values is not substantial, suggesting that targeted treatment or processing could improve their suitability.

These shape-related properties play a significant role in determining both porosity and permeability of the proppant pack. Although the samples analyzed (Table 4-11) do not fully meet the ideal specifications, their performance may still be acceptable under certain operating conditions. At low closure stresses, the influence of roundness and sphericity becomes less critical.

4.3 Mineralogy

4.3.1 X-Ray Fluorescence

The X-Ray Fluorescence analysis of the bulk chemical composition of all samples is shown in Table 4-12.

Table 4-12. Chemical Composition of Sand Samples

Contents (Weight %)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
SiO ₂	93,270	90,840	88,120	91,340	92,980	82,960	91,220	42,190
Al ₂ O ₃	6,020	8,060	5,300	6,330	5,140	14,940	6,420	52,980
K ₂ O	0,045	0,187	1,470	1,000	0,880	1,180	1,340	0,067
Cr ₂ O ₃	0,078	0,115	0,013	0,004	0,004	0,003	0,004	0,011
Fe ₂ O ₃	0,568	0,771	0,738	0,950	0,680	0,900	0,990	1,730
ZrO ₂	0,0203	0,0273	0,0032	0,0252	0,0233	0,0233	0,023	0,034
CaO	Nil	0,3293	1,53	0,0374	0,0344	0,0359	0,0359	0,141
MgO	Nil	Nil	0,904	0,0961	0,0966	0,0884	0,0884	Nil
TiO ₂	Nil	Nil	1,436	0,0996	0,0897	0,126	0,126	3,13
MnO	Nil	Nil	0,009	0,0959	0,118	0,134	0,134	Nil
Rb ₂ O	Nil	Nil	0,003	0,047	0,0369	0,0437	0,0437	Nil
P ₂ O ₅	Nil	Nil	0,4	Nil	Nil	Nil	Nil	0,564
V ₂ O ₅	Nil	Nil	0,068	Nil	Nil	Nil	Nil	0,0258
SrO	Nil	Nil	0,0061	Nil	Nil	Nil	Nil	Nil

4.3.2 X-Ray Diffraction

The XRD patterns that identify the crystalline phases present, are illustrated in Figures 4-1 to 4-8.

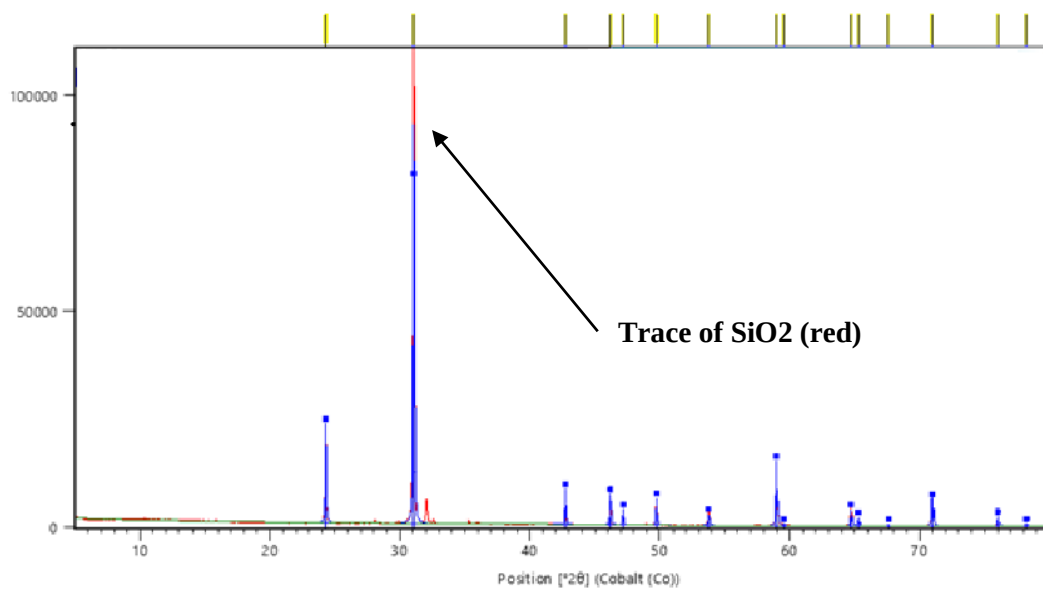


Figure 4-1. XRD Analysis of Sample 1

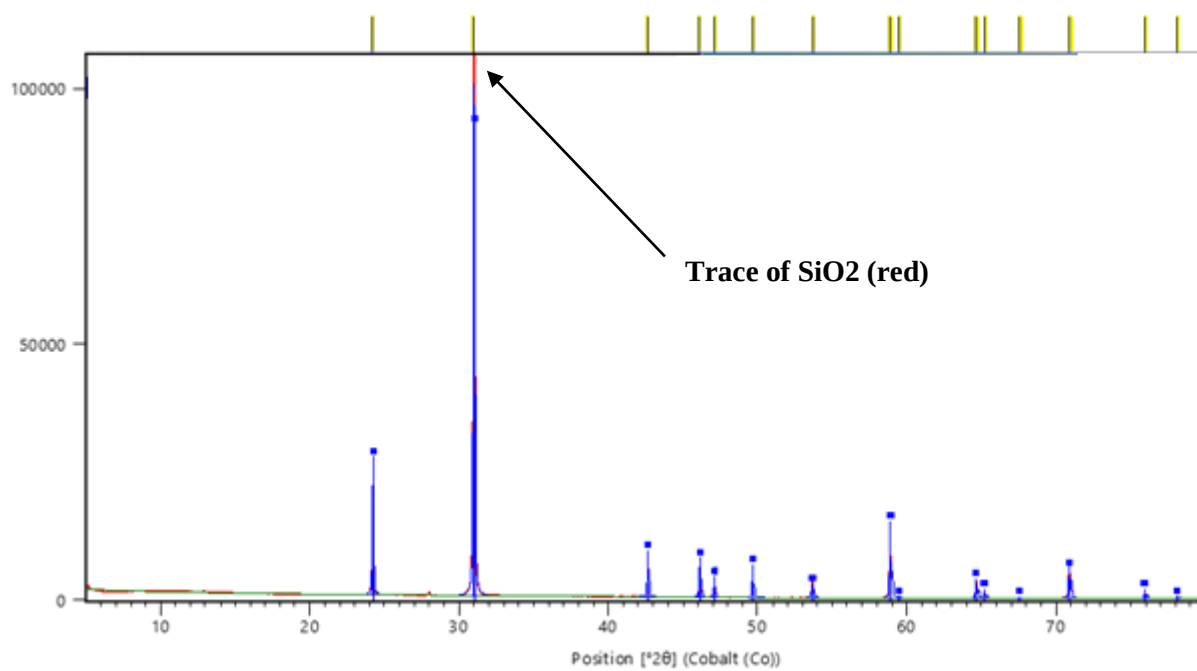


Figure 4-2. XRD Analysis of Sample 2

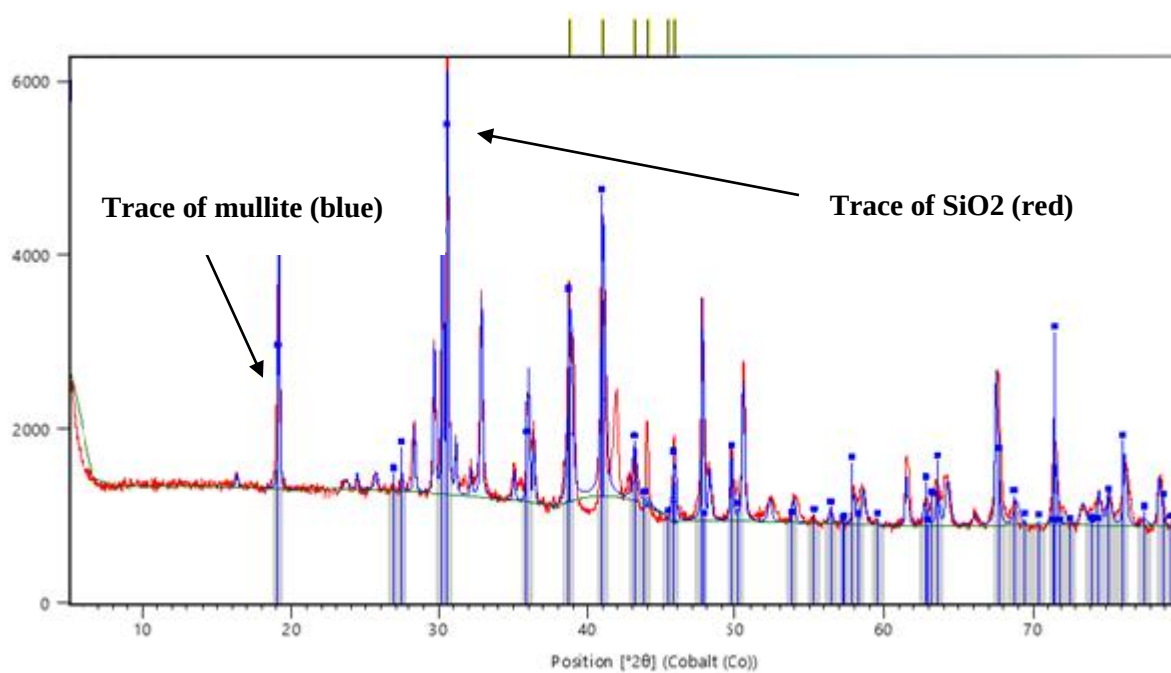


Figure 4-3. XRD Analysis of Sample 3

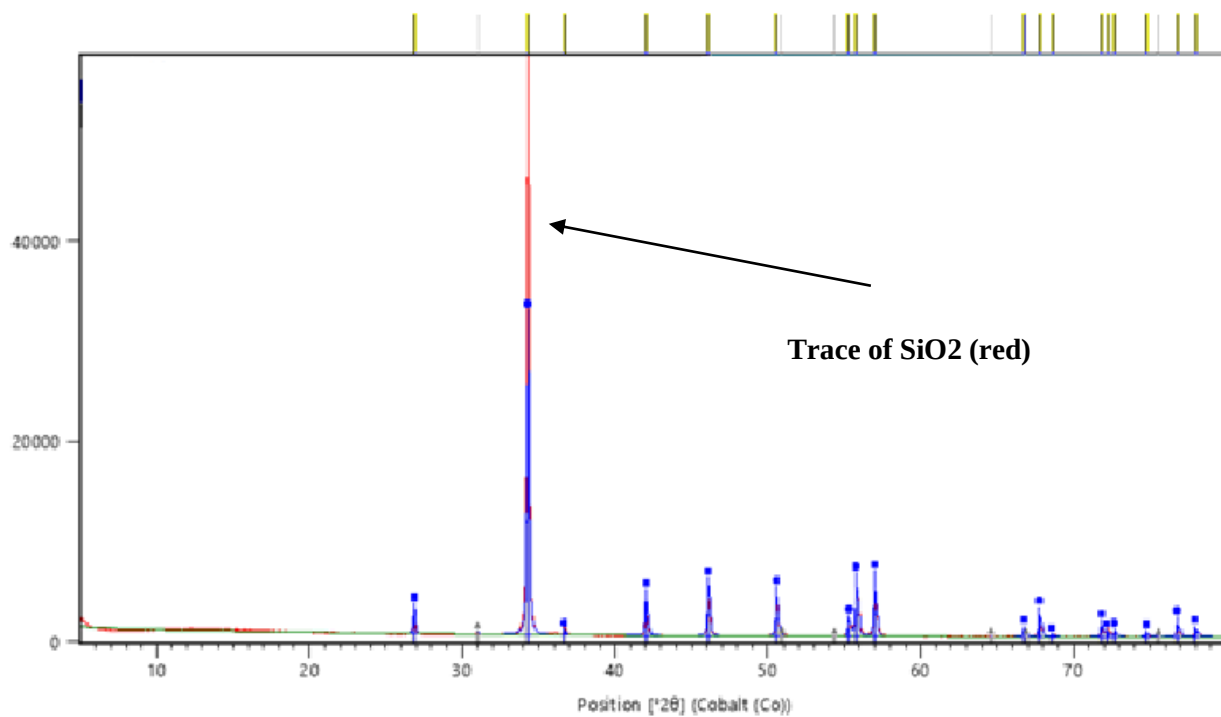


Figure 4-4. XRD Analysis of Sample 4

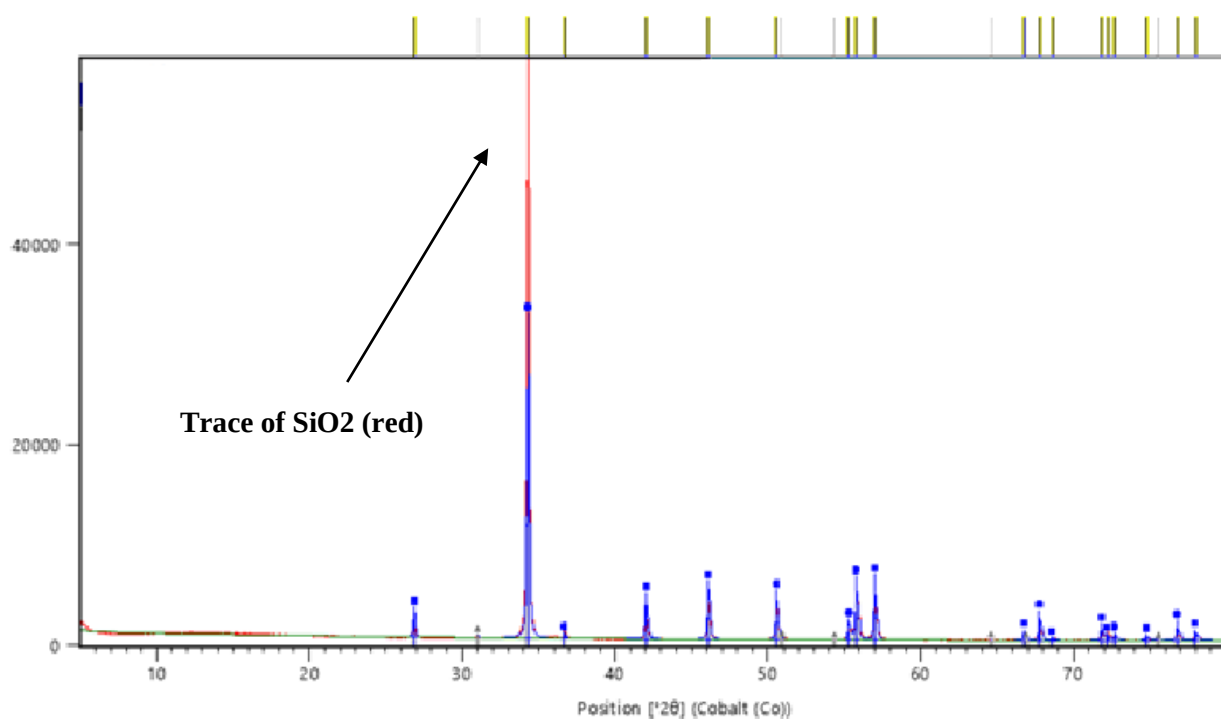


Figure 4-5. XRD Analysis of Sample 5

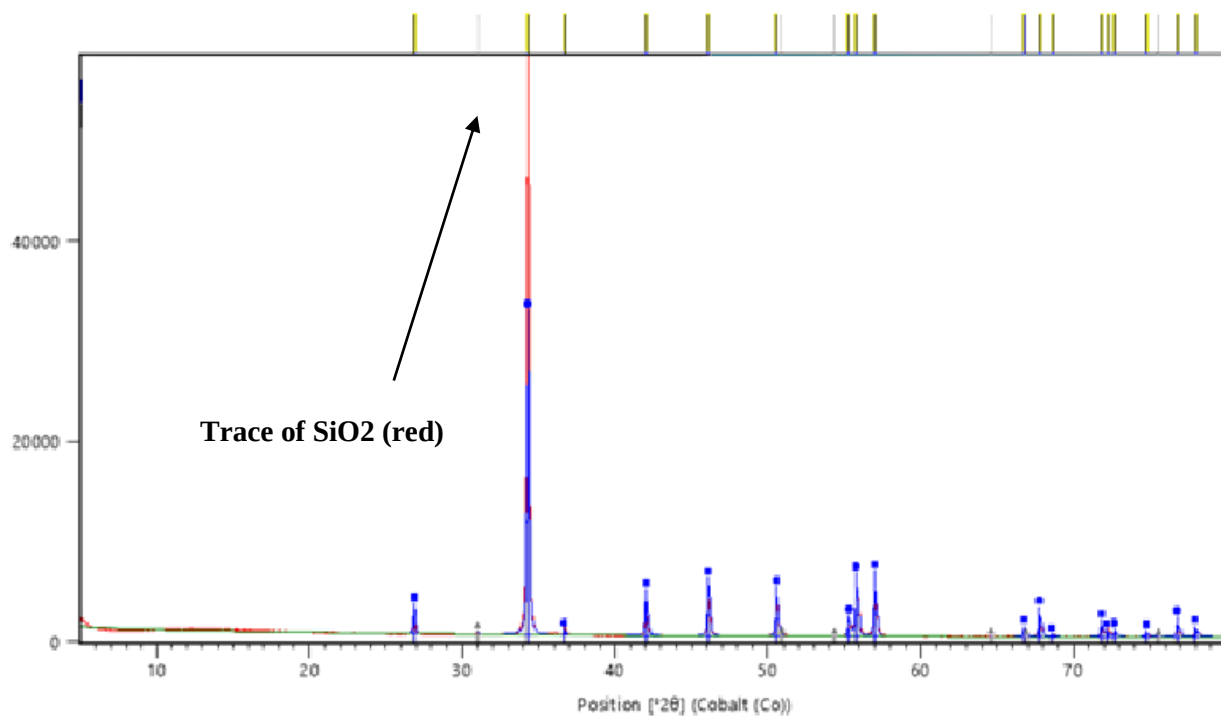


Figure 4-6. XRD Analysis of Sample 6

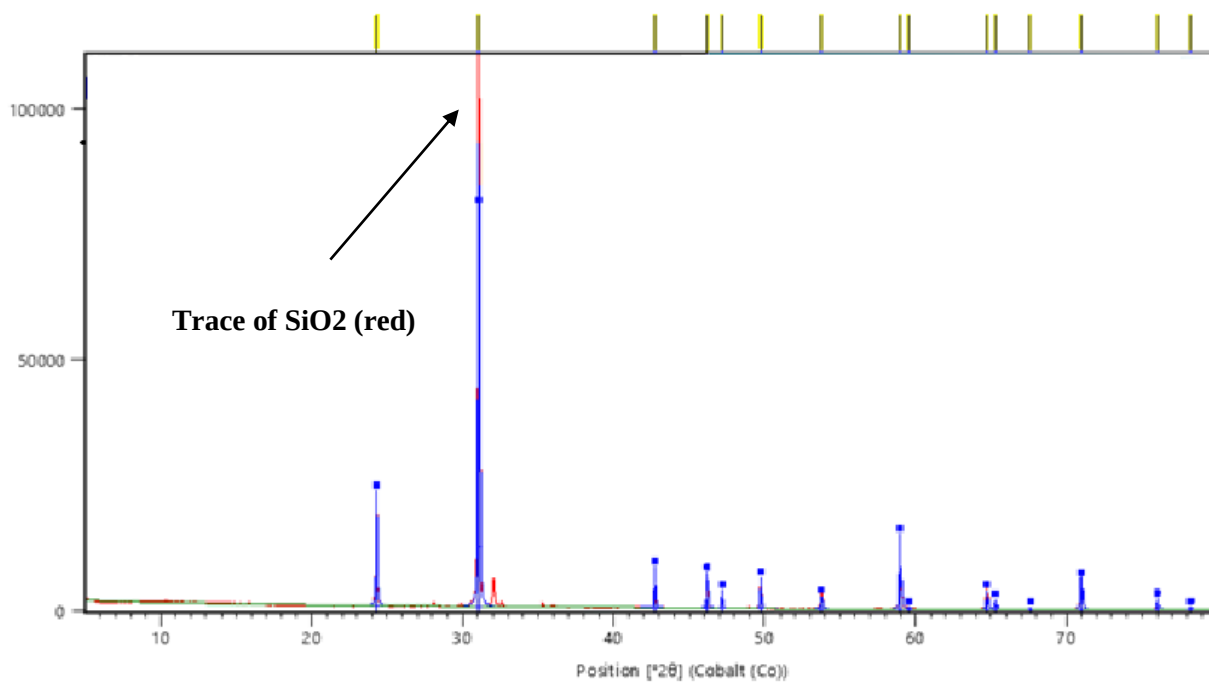


Figure 4-7. XRD Analysis of Sample 7

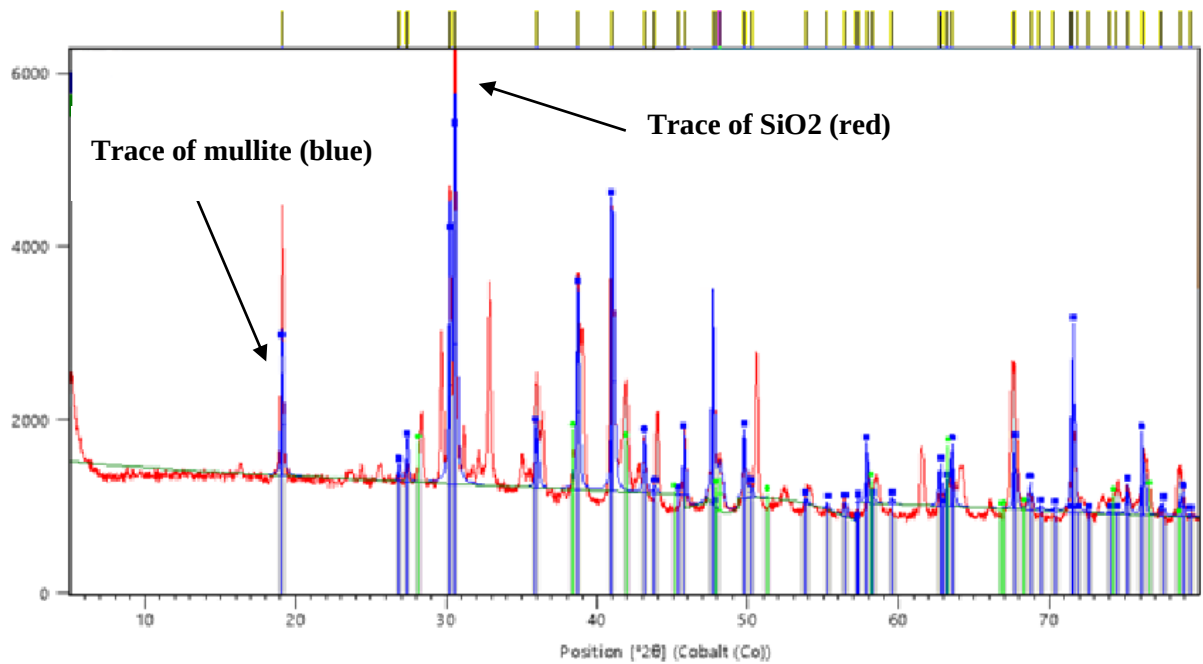


Figure 4-8. XRD Analysis of Sample 8

4.3.3 Summary of XRF and XRD results

The important findings of the XRF and XRD analyses are summarized in Table 4-13.

Table 4-13. Summary of XRF and XRD Results

Sand Samples	Percentage of SiO ₂ (XRF)	Trace of SiO ₂ (XRD)
Sample 1	93,270	Yes
Sample 2	90,840	Yes
Sample 3	88,120	Yes
Sample 4	91,340	Yes
Sample 5	92,980	Yes
Sample 6	82,960	Yes
Sample 7	91,220	Yes
Sample 8	42,190	Yes

XRF analysis confirms that local samples 1–7 are high-purity silica sands, with SiO₂ content ranging from 82.96% to 93.27%. Sample 8 (Commercial) has a lower silica content (42.19%) but a very high alumina content (52.98% Al₂O₃). XRD confirmed the presence of silica in all samples, but only Sample 8 contained traces of mullite.

High SiO₂ indicates natural geochemical stability. The presence of mullite and high Al₂O₃ in Sample 8 identifies it as a sintered ceramic proppant, which is man-made to provide

superior mechanical strength compared to natural sand (Suhaimi, 2013). The local sands (especially Sample 1 at 93.27% SiO₂) are excellent candidates for natural sand proppants, though they lack the engineered strength of the ceramic commercial sample.

4.4 Bulk Density

The graded cylinder method was used to measure the bulk density of each sample. The calculated data are given in Table 4-14.

Table 4-14. Bulk Density of Sand Samples

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Mass of empty 100 ml cylinder, g	127,54	127,54	127,54	127,54	127,54	127,54	127,54	127,54
Mass of 100 ml cylinder + sand sample, g	276,65	280,12	286,42	279,6	273,62	283,58	278,65	287,46
Mass of sand sample, g	149,11	152,58	158,87	152,06	146,08	156,04	151,11	159,91
Bulk Density of sand sample, g/cc	1,49	1,53	1,59	1,52	1,46	1,56	1,51	1,60

The bulk density of local Kazakhstan samples is relatively consistent, ranging from 1.46 to 1.59 g/cc. This is slightly lower than the commercial Sample 8 (1.60 g/cc) in Table 4-14. Lower-density proppants are advantageous because they are easier to suspend and transport within fracturing fluids, potentially creating longer effective transport lengths. In silica sands, bulk density typically increases with particle size. The proximity of local sand density to commercial values suggests they would behave similarly during fluid transport.

4.5 Turbidity

The results of turbidity analysis are shown in Table 4-15 against the API RP 56 requirement limit of <250 NTU.

Table 4-15. Turbidity of Sand Samples

Samples	Turbidity, NTU
Sample 1	223
Sample 2	177
Sample 3	214
Sample 4	234
Sample 5	110

Sample 6	198
Sample 7	245
Sample 8	223

All samples passed the API RP 56 turbidity requirement of < 250 NTU. Local values ranged from a very clean 110 NTU (Sample 5) to 245 NTU (Sample 7).

Turbidity measures the number of suspended particles, such as silt and clay. Low turbidity is critical because these fines can migrate and plug the proppant pack, drastically reducing fracture conductivity over time. The results indicate that Kazakhstan sands are sufficiently clean for hydraulic fracturing applications.

4.6 Crush Resistance

The crush resistance of all samples was measured under increasing closure stresses between 500 and 3000 psi. Table 4-16 provides the percentage of fines generated at each stress level, and Figure 4-9 plots the percent of fines generated at each stress level.

Table 4-16. Crush Results for Sand Samples

Pressure, psi	% of Fine							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
500	2,735	5,35	0	3,256	2,621	1,916	2,427	0
1000	8,921	15,64	0	8,816	8,452	8,97	8,622	0
1500	12,942	21,769	2,451	15,254	16,678	15,78	14,963	-
2000	15,985	28,567	3,971	18,833	20,817	20,474	19,633	5,034
2500	20,385	30,796	7,554	21,789	23,832	22,487	23,265	7,346
3000	23,076	33,215	10,65	25,431	24,583	30,49	29,645	10,437

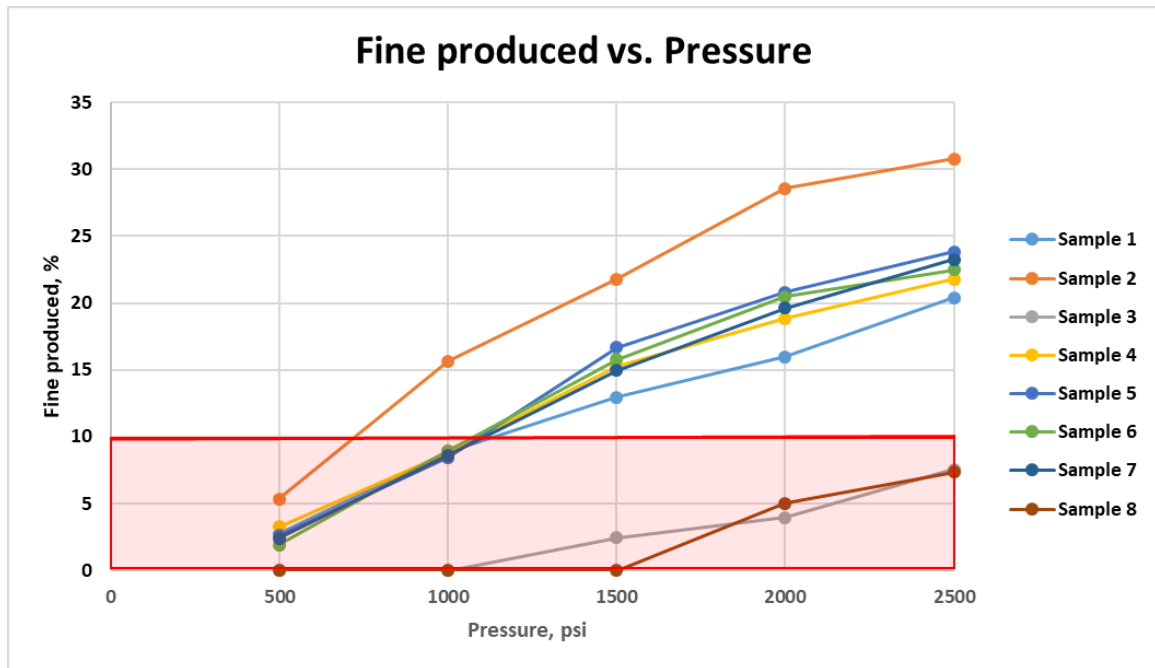


Figure 4-9. Crush Resistance Comparative Graph

All samples showed an increase in fines production as pressure rose from 500 to 3000 psi. Sample 8 (Commercial): Most resistant, staying well below the 10% fine limit until 3000 psi. Sample 3 (Local): The strongest local sample, producing only 10.65% fines at 3000 psi. Others (Samples 1, 2, 4–7): Most exceeded the 10% limit at pressures above 1000–1500 psi.

API standards only allow a maximum of 10% fines. Most local Kazakhstan sands are suitable only for low-closure stress reservoirs (< 1500 psi). The high fines production in local samples is attributed to their more angular grain shape, which crushes more easily than the rounded commercial proppant. Sample 3's relative strength suggests it has the highest potential for use without intensive modification.

4.7 Permeability and Conductivity

The qualitative assessment of permeability and conductivity of the proppant packs was conducted using a benchtop permeameter at zero confining stress. The findings are given in Table 4-17. As has been mentioned in the methodology, these values are not API RP 19D compliant and can be used only to conduct internal, qualitative comparison.

Table 4-17. Conductivity Results for Sand Samples

	Permeability	Conductivity	
		mD.cm	mD.ft
Sample 1	652	1656,08	54,31
Sample 2	671	1704,34	55,89
Sample 3	785	1993,90	65,39

Sample 4	540	1371,60	44,98
Sample 5	626	1590,04	52,15
Sample 6	830	2108,20	69,14
Sample 7	714	1813,56	59,48
Sample 8	845	2146,30	70,39

Samples 3, 6, and 8 have the highest value of conductivity as compared to other samples. Remember that the equipment used in this specific test of the conductivity is not the normal equipment used in proppant testing. For this reason, the dependency on the accuracy of the results is still questionable. However, the outcome of this experiment ought to provide a good preliminary suggestion on the qualitative evaluation of the samples.

4.8 Summary of Compliance with API RP 56/58

The table below is a summary of the performance of all the eight samples in comparison with the key API RP19, API RP56, and API RP58 requirements (API, 1995a; 1995b). Only when a sample fulfils all the requirements of a certain parameter, it is considered PASS. FAIL means that the value measured is not within the API specified limit. Table 4-18 shows this compliance overview.

Table 4-18. Compliance of Kazakhstan sand samples with API RP 56/58 criteria (PASS/FAIL)

Parameter	API Limit	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Particle size distribution ($\geq 90\%$ within mesh)	$\geq 90\%$	PARTIAL	PARTIAL	PASS	FAIL	FAIL	FAIL	FAIL	PASS
Sphericity (Krumbein)	≥ 0.6	FAIL (0.6)	FAIL (0.6)	PASS (0.7)	FAIL (0.5)	PASS (0.7)	PASS (0.7)	FAIL (0.6)	PASS (0.9)
Roundness (Krumbein)	≥ 0.6	FAIL (0.5)	FAIL (0.5)	PASS (0.7)	FAIL (0.5)	PASS (0.8)	PASS (0.8)	FAIL (0.6)	PASS (0.9)
Turbidity	< 250 NTU	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Crush resistance ($\leq 10\%$ fines)	$\leq 10\%$ at max stress	FAIL (> 1500 psi)	FAIL (> 1500 psi)	FAIL* (10.65% at 3000 psi)	FAIL (> 1000 psi)	FAIL (> 1500 psi)	FAIL (> 1500 psi)	FAIL (> 1500 psi)	PASS (to 3000 psi)

Bulk density (g/cc)	(no absolute limit)	1.54	1.57	1.50	1.59	1.46	1.49	1.59	1.60
API RP 19D conductivity	(applicati on-depend ent)	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested

No local Kazakhstan sand sample meets all API RP 56/58 criteria simultaneously. Sample 3 (Oral region) shows the best combination of sphericity, roundness, and crush resistance, but still fails the API crush limit at 3000 psi. All local samples require additional processing (industrial sieving, resin coating) to become fully compliant. The commercial ceramic proppant (Sample 8) passes all tested parameters.

5. DISCUSSION

5.1 Morphological and Mineralogical Suitability of Kazakhstan Sands

The XRF results (Table 4-12) show that local samples 1–7 have SiO₂ contents between 82.96% and 93.27%, confirming that they are high-purity quartz sands. Sample 1 (Mangystau) is purest (93.27% SiO₂), similar to commercial Ottawa sand that is usually over 95% SiO₂ (Suhaimi, 2013). Large silica content is preferable as quartz is stable to most conditions in the reservoir and is non-dissolvable in acidic fracturing fluids.

Nevertheless, a high level of SiO₂ is not a sure indicator of good proppant behaviour. SEM photomicrographs (Table 4-10) and Krumbein analysis (Table 4-11) indicate that morphological variability is significant:

Sample 5 and 6 (Karaganda, depth 1.0–0.21) are the most rounded (0.8) and the most spherical (0.7) samples, and satisfy API RP 56 minimum (0.6) requirements.

Sample 4 (Karaganda, 0.3 m) is the most angular (roundness 0.5, sphericity 0.5), and significantly below the API threshold.

Sample 1, 2, and 7 contain borderline roundness/sphericity (0.5–0.6), which do not satisfy or even meet the standard.

The angular grains, according to Alramahi and Sundberg (2012), cause local stress peaks at sharp corners, which are up to 3–5 times greater than the average applied stress. These hotspots lead to premature crushing of grain and generation of fines, even at moderate closure pressures. By contrast, spherical grains (e.g., Sample 8, roundness 0.9), spread the stress uniformly over the surface, and postpone crush failure.

Practical implication: sands that are local and roundness less than 0.6 (Samples 1, 2, 4, 7) would need shape enhancement - probably through resin coating, adding a compressive layer that would enhance the effective contact area and minimize loading of points (Montgomery, 2019). These angular sands will tend to produce excess fines when they are not coated and they are subjected to realistic closure stresses (>2000 psi).

5.2 Standards Crush Resistance - The Main Technical Limitation

The most discriminating parameter of this study is the crush resistance test (Table 4-16, Figure 4-9). Key observations are Sample 8 (commercial ceramic) has fines of less than 10 percent to 3000 psi, which confirms its high-strength classification. Sample 3 (Oral region) is the largest local sand with the most 10.65% fines at 3000 psi - just above the 10% API threshold. All other local samples contain more than 10 percent of fines at 1000–1500 psi.

The API limit of 10 percent fines is not arbitrary, but has empirical correlations between laboratory crush tests and field conductivity loss. Wang et al. (2025) demonstrated that a 1% change in fines above 10% decreases proppant pack permeability by an average of 5-8 percent at cyclic stress. Thus, a sample that yields 15 per cent fines at 2000 psig would lose 25-40 per cent of original conductivity in weeks of production.

The closure stresses of many Kazakh oil fields (ex: Mangyshlak Basin, South Turgay Basin) range between 3000 and 6000 psi at common reservoir depths (2000-4000 meters). Based on the crush data:

- In this study, no local sand can be used in a reservoir with a closure stress greater than 2000 psi without modification.
- Sample 3 may be used in low-stress reservoirs (below 2500 psi) or as a bottom sand to coat with resin.
- Samples 1, 2, 4-7 are limited to very shallow reservoirs (<1500 psi) or non-proppant applications (e.g., gravel packing).

This is in line with the experience of the rest of the world: most natural sands need to be beneficiated (sieved, coated) to be utilized at 2000 psi and more (Shafiq et al., 2025).

5.3 Particle Size Distribution and Its Effect on Pack Permeability

The sieve analysis (Tables 4-2 and 4-9) indicates that Sample 3 and Sample 8 only have a tight particle distribution with a 90- percent distribution in the 20/40 mesh range. The Karaganda samples (4- 7) are not well sorted, much of the mass being left on the sieves.

Why poor sorting is problematic: Large particle size distribution means that small grains can fill the pore space between large grains and make it less porous and less permeable. The coefficient of uniformity ($C_u = D_{40}/D_{90}$) should preferably be below one and a half as outlined in API RP 56. Poorly sorted packs may have 30-50% permeability of well sorted packs with the same median grain size (Suhaimi, 2013).

Recommendation: the local sands that are supposed to be used as proppant should be sieved to a fine range of mesh size (e.g., 20/40 or 30/50) on an industrial scale. This is the norm even of high-quality Ottawa sand and does not represent a technical challenge, just cost addition.

5.4 Turbidity, Bulk Density, and Other Physical Properties

All local samples exceeded the turbidity threshold of <250NTU (Table 4-15) with Sample 5 exhibiting outstanding purity (110NTU). This means that silt and clay are very low and that is significant because the fines of clay can move and block the throats of the pore even though the proppant is not crushed (Penny, 2017).

Local sands have a bulk density (Table 4-14) of 1.46-1.59 g/cc, which is a bit lower than that of the commercial ceramic (1.60 g/cc). Reduced density is operationally advantageous due to the enhanced fracture half-length proppant transport in low-viscosity slickwater fracturing fluids, possibly enabling longer effective fracture half-lengths (Bandara et al., 2021).

5.5 Permeability and Conductivity — A Critical Caveat

According to Section 3.3.7, the measurements of benchtop permeability (Table 4-17) were conducted at zero stress of closure and are not in compliance with API RP 19D. Hence, field fracture conductivity cannot be predicted based on the numerical values. The only possible conclusion of Table 4-17 is that in ideal (zero-stress) conditions, Sample 3, 6, and 8 are the most permeable to water. But in actual closure stress, the ranking would most probably be altered since the crush resistance and angularity would be dominant.

Recommendation for future work: any company planning to use local sands in hydraulic fracturing should follow API RP19D conductivity tests with a servo-controlled press with closure stress cycling (up to 6000 19D) and reservoir temperature (e.g. 95 C). In the absence of these data, there can be no reliable prediction of conductivity.

5.6 Implications for Formation Damage and Fracture Face Skin (FFS)

The combination of angularity and poor crush resistance in most local samples suggests a high risk of mechanically induced fracture face skin (FFS) in soft Kazakh reservoirs (e.g., Mangyshlak unconsolidated sandstones).

Mechanism (from Reinicke, 2011): angular proppant grains create stress concentrations at the fracture face. Under closure stress, these hot spots crush the rock matrix, generating fine particles. The fines migrate into the proppant pack and block pore throats, creating a low-permeability skin. Laboratory studies have shown that FFS can reduce near-fracture permeability by 80–90% within 50 hours of stress application (Penny, 2017).

Mitigation strategies based on this study on Table 5-1:

Table 5-1. Mitigation strategies

Problem	Measured in this study	Recommended solution
Low roundness/sphericity	Samples 1, 2, 4, 7 (0.5–0.6)	Resin coating (deformable layer)
High fines at >1500 psi	All except Sample 3	Resin coating OR use only in shallow reservoirs (<1500 psi)
Poor size sorting	Samples 4–7	Industrial sieving to narrow mesh range

Resin coating is particularly effective because it serves two purposes: (1) it increases effective roundness by filling angular voids, and (2) it encapsulates individual grains, so even if the sand core fractures, the coating holds the fragments together, preventing fines release (Montgomery, 2019).

5.7 Comparison with International Literature

Kazakhstan sands performance is in line with other studies in the region. Sobri (2013), Suhaimi (2013) described Malaysian sands and had similar restrictions: sufficient purity of SiO₂, but low roundness and resistance to crushing higher than 2000 psig. Khair et al. (2017) also indicated that Sudanese Bayuda sand had to undergo beneficiation in order to utilize it in proppant.

In this study, what is new: the present systematic API-compliant characterization of the sands of four different regions of Kazakhstan (Mangystau, Aktobe, Oral, Karaganda) through the same laboratory protocols is the first. The data gives a starting point as to which future proppant development in Kazakhstan should be.

5.8 Limitations

The following limitations must be admitted: There was no direct measure of interaction between proppant and reservoir rock. Sample size — the sample size was only eight samples; it should be expanded to regional samples. Despite these constraints, the study was able to characterize the physical, morphological and mechanical characteristics of Kazakhstan sands in comparison with API standards which gave a clear roadmap of how it may be used as hydraulic fracturing proppants.

6. CONCLUSION AND RECOMMENDATIONS

Eight sand samples of Kazakhstan were characterized as per API RP 56/58. Conclusions made include:

- Mineralogical purity: SiO₂ contents of 83-93 in local sands testify to high levels of quartz purity and geochemical stability.
- Morphological constraints: Roundness is 0.5-0.8, and sphericity 0.5-0.7. Samples 3, 5 and 6 are the only samples that satisfy the API minimum of 0.6 in the two parameters. Angular grains (Samples 1, 2, 4, 7) are susceptible to point loading and premature crushing.
- Crush resistance: Most local samples have crush resistance beyond 10 per cent API fines at closure stress greater than 150038 psi. Sample 3 (Oral region) is the best local candidate (10.65% fines at 3000 psi) but fails with 3000 psi. Local sample does not reach API crush resistance at >2000 psi.
- Turbidity and bulk density: Turbidity limit (<250 NTU) is crossed in all samples. Bulk densities (1.461.59 g/cc) are a little bit less than the commercial ceramic (1.60 g/cc), which is advantageous in transportation.
- Particle size distribution: Samples 3 and 8 only have 90% in a small mesh range. Samples with bad sorting (47) must be sieved industrially.
- Permeability/conductivity: The benchtop measurements under zero stress are not API RP 19D compliant and cannot be used for field predictions.

Recommendations

In case of industry (immediate application):

- Only under low-stress reservoirs: Unmodified low-stress reservoirs: Raw Kazakhstan sands (particularly Sample 3) can be utilized in reservoirs with closure stress under 1500 psi.
- Resin coating: In reservoirs where the closure stress is 1500-4000 psi, it is recommended that resin-coated versions of Samples 3, 5, or 6 be used. Coating enhances good roundness and inhibits release of fines.
- Industrial sieving: All local sands need to be sieved to a small mesh size (e.g., 20/40 or 30/50) prior to use.

To continue with the research (next steps):

- API RP19D conductivity tests: These should be done with real Kazakh core samples under closure stress (to a maximum of 6000 psi) and at reservoir temperature (at least 95°C).
- Acid solubility test: According to API RP 56, to test the resistance to stimulating fluid.

- Geopolymer proppants: Kazakhstani fly ash (Ekibastuz power plants, Karaganda) must be experimented in producing lightweight proppant.
- Pilot field experiments: Raw or resin-coated local sands should be tested in first field experiments in shallow wells in the Mangyshlak Basin (<1500 ϕ closure stress).
- Embedment studies: Direct measurement of proppant embedment in confining stress Kazakh reservoir core samples.

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