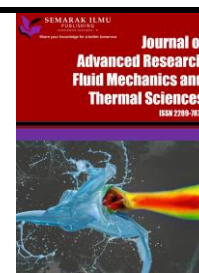




Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Quartz Hydrolysis Analysis of Pure Quartz for Enhanced Oil Production; Influence of Time, pH, and Salinity on Hydrolysis

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ARTICLE INFO

Article history:

Received 19 August 2023

Received in revised form 27 October 2023

Accepted 10 November 2023

Available online 30 November 2023

Keywords:

Silica dissolution; sand production control; water breakthrough; semi-consolidated formation

ABSTRACT

The issue of sand production in reservoirs has been recognized as a critical problem in oil and gas fields for several years due to its numerous negative impacts on oil and gas production. Sand production from wells can damage both surface and subsurface equipment, reduce well productivity, and negatively impact the oil production economy. Oil production challenges arise when sand production increases as the water cut increases. Several factors have been associated with this phenomenon, with the most critical factor being silica dissolution - a chemical reaction between quartz and water that decreases formation strength. This study explores the dissolution of silica on pure quartz and the effects of added electrolyte (NaCl, CaCl₂, MgCl₂, and KCl) concentration, temperature, and pH on the dissolution process. The concentration of silica dissolved in solution was measured using UV-Vis spectrophotometry to determine the dissolution of silica on quartz. The results outcome indicate that the rate of silica dissolution is significantly influenced by variations in temperature and alterations in pH levels. The salinity conditions exhibit minimal alterations in comparison to distilled water. The highest concentration of silica dissolved in a solution has been seen at pH levels of 12 and 3, with concentrations of 118 mg/l and 68 mg/l, respectively. In terms of temperature, it was observed that there was an increase in the dissolution of silica from 30°C to 90°C, ranging from around 170% to 600%. Regarding salinity, it can be shown that NaCl and KCl exhibit the most significant impact on silica dissolution when compared to other brine solutions, with concentrations of 45 and 49 mg/l, respectively. The study claims that the formation strength may be influenced by water quality through the processes aimed at stimulating or lowering silica dissolution. Therefore, the optimal water quality design for water injection is paramount in mitigating sand production challenges.

1. Introduction

Sand production is a common concern throughout the life of oil and gas wells and is more likely to occur in poorly consolidated sands [1]. Sand production may adversely affect the excellent completion due to plugging perforations or production liners, wellbore instability, and failure of sand

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<https://doi.org/10.37934/arfmts.111.2.99106>

control completions [2]. In addition, sand-related problems increase production costs considerably by causing erosion of pipelines and surface facilities, reduced productivity, intervention costs and complexities, and other environmental effects [3].

Sand production is identified as both mechanical and fluid flow effects. The mechanical impact involves mechanical instability and degradation around the wellbore/perforation caused by shear, tensile, or compressive failure [3,4]. This relates to stresses, and rock strength [5]. Sand production happened because of the shear failure, which occurs on the surface of the rock (i.e., borehole surface) due to high shear stress. During production, the induced shear failure surfaces are mobilized, and sand debris is produced due to drag forces caused by the reservoir fluid flow. The produced sand will then flow into the well and the reservoir fluids [6]. In unconsolidated and weak formations, production occurs when the drag forces caused by the flowing reservoir fluids overcome the natural inherent cohesion of the formation [7]. Furthermore, an increase in water-cut in the reservoir formation during the late life of the reservoir is unavoidable, be it because of water injection or water coning [8]. The injection of water/brine will increase the water cut and minimize the capillary pressure that exists between the water and the capillary fluid and rock strength [9].

The consequence of water cuts on sand production has been a significant concern in the oil and gas industry. It has been seen in numerous events in the field that the initiation of sand production coincides with water breakthrough [10]. The effect of water cut on sand production has been an area of research for several years, and several mechanisms have been hypothesized to explain the effect [1,9,11-13]. Water flooding is an improved oil recovery method that operates at a lower cost than other recovery methods. Water flooding has been widely implemented in sandstone oil reservoirs to support pressure and improve oil displacement efficiency. However, Sand production is highly related to an increase in water saturation and is considered a common problem in oil fields, especially for weakly consolidated sand; when the mobility of water is more significant than oil, the water-oil interface sees the upward movement of water into the perforations of a producing well [14].

The predominant mineral in the sandstone reservoir is quartz (SiO_2), which is the most common silica crystal and the second most common mineral on the surface of earth. The quartz (silica) has a relationship with water, weakening the silica structure by a chemical reaction between water and quartz called quartz hydrolysis. Chemical reactions can be divided into two types: one group is the interaction between rock skeleton and water; the other is between cementation minerals and water. Both could reduce rock stability by decreasing rock strength [9,15,16]. Quartz hydrolysis chemical reaction between quartz and water is shown in Eq. (1).



This paper aims to evaluate the impact of pH and electrolytes (including NaCl, CaCl_2 , MgCl_2 , and KCl) at various concentrations on quartz hydrolysis (silica dissolved) during a chemical reaction between quartz and water. The outcomes of this study will lead to a better understanding of the geochemical processes taking place in reservoirs and offer insightful information on the mechanisms underlying silica dissolution, which leads to sand production.

2. Material and Methods

2.1 Materials

The dissolution test was conducted using pure quartz (SiO_2). This quartz, which is purer than 99.8%, was acquired from the Lingshou Jiaqi Mineral Processing Factory (Shijiazhuang). Two types of quartz were available: coarse particles with a diameter of 200 μm and small particles with a diameter

of 50 μm . Four salts, including sodium chloride (NaCl), calcium chloride (CaCl_2), potassium chloride (KCl), and magnesium chloride (MgCl_2), were used to explore how brine concentrations affected silica dissolution. Without further purification, these salts came from trustworthy suppliers, including QREC (Selangor, Malaysia) and Merck Chemicals (Germany).

2.2 Quartz Hydrolysis Reaction Study

The approach of this study is to evaluate quartz hydrolysis reaction throughout many batch experiments utilizing 15 g of crushed quartz to 45 ml of distilled water [17]. This water has been mixed with various solutions. The solutions have different brine types (NaCl , KCl , MgCl_2 , CaCl_2) at various concentrations (200, 400, and 800 ppm). As shown in Figure 1, the solutions were prepared and combined in a 250 ml container, submerged in a water bath, and agitated at 170 revolutions per minute for 60 hours at ambient temperature. The centrifugation technique was used to separate temperature-sensitive quartz particles from the solution, followed by a UV-Vis Spectrophotometer DR3900 to quantify the silica concentration.

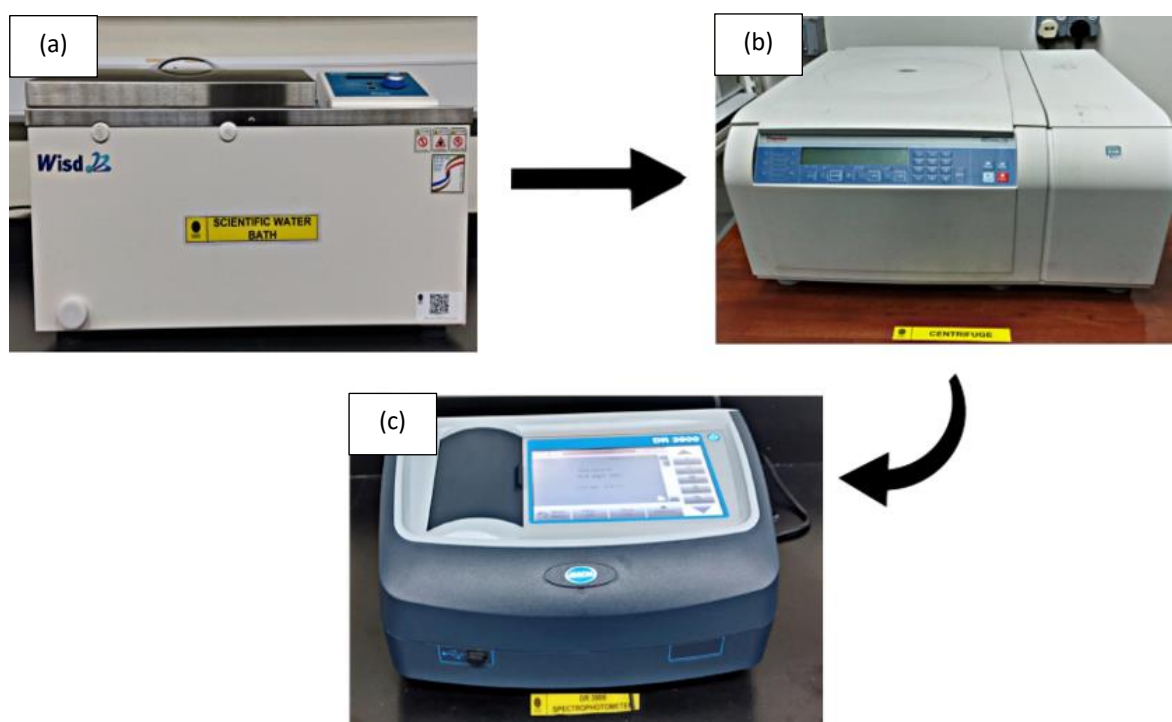


Fig. 1. Experimental set-up for the silica dissolution experiments showing (a) water bath (b) Thermo Scientific Multifuge X1R Centrifuge (c) UV-Vis Spectrophotometer DR3900

3. Results and Discussion

3.1 Quartz Characterization Test

The mineralogy of a rock sample, as determined by X-ray diffraction (XRD) examination, plays a crucial role in identifying the surface charge of the rock [18,19]. The X-ray diffraction (XRD) analysis confirms that the sample's predominant form of silicon oxide is quartz, as shown in Figure 2, with about 97.7% composition. The remaining 0.3% of the sample consists of various oxides. The statement verifies that the quartz used in the experiment was composed of pure quartz and consisted of silicon oxide.

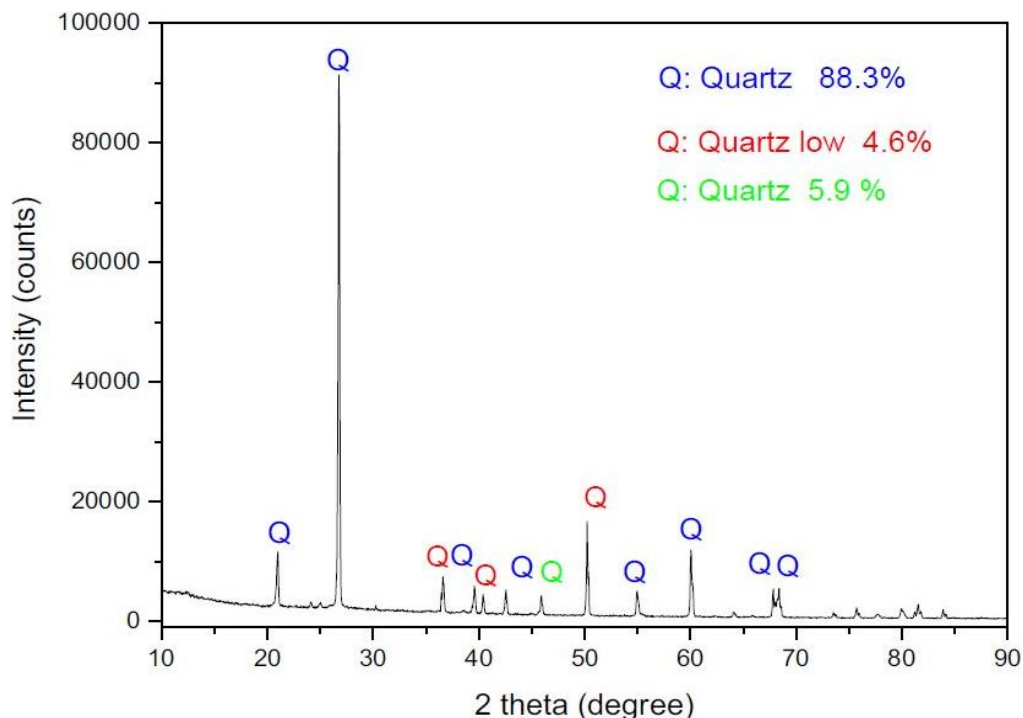


Fig. 2. X-ray diffractogram image of quartz

3.2 The Time Impact on Quartz Hydrolysis

Figure 3 illustrates the behavior of silica dissolution with different time intervals in distilled water at ambient temperature. The main objective of this test is to determine the time required for the reaction between quartz and water to achieve equilibrium. The silica dissolution started with around 25 mg/l silica dissolved at 24 hours. The trend gradually increased as time increased until around 38 mg/l at 48 hours. The peak has been reached at 60 hours with 45 mg/l silica dissolved; once the duration of the reaction exceeds 60 hours, no further chemical reactions occur, indicating that the process has reached equilibrium and no additional reaction will proceed. Based on the observed graph pattern, it can be inferred that the optimal time for achieving equilibrium in the quartz hydrolysis reaction is approximately 60 hours—the rationale for selecting a fixed duration of 60 hours for conducting experiments.

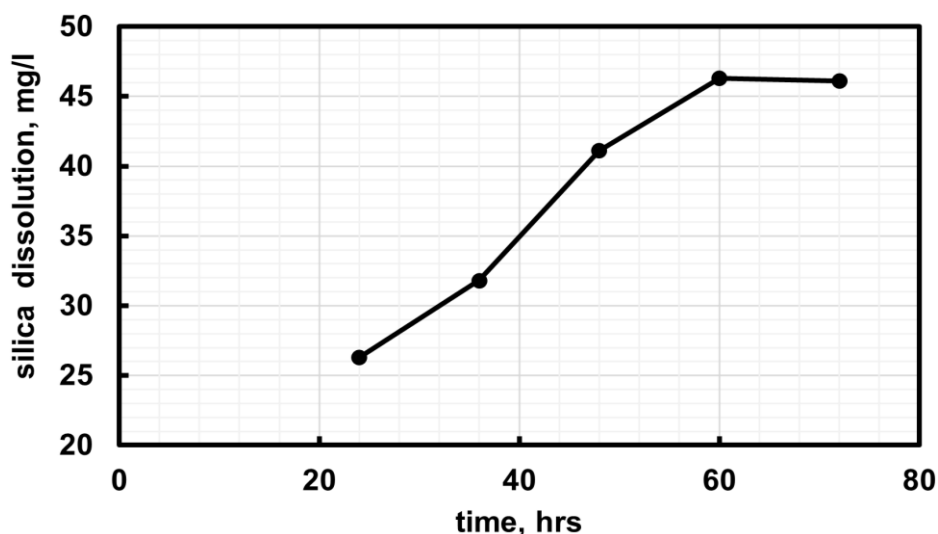


Fig. 3. Impact of time on quartz hydrolysis at ambient temperature

3.3 The Impact of Changing pH Solutions on Quartz Hydrolysis

pH is the most crucial parameter in a chemical reaction. In addition, the particle size of rock has a main role in increasing or decreasing the reaction speed. Therefore, the effect of pH on quartz hydrolysis in coarse and fine particles using distilled water solution at ambient temperature is shown in Figure 4 and Figure 5.

Figure 4 shows that silica dissolution (coarse particles) is highly affected by pH, especially alkaline regarding coarse particles. The observed pattern indicates a positive correlation between pH levels and silica dissolution. This correlation is evident when the pH increases, increasing the amount of silica dissolved. The dissolution of silica continues to rise until it reaches its peak at a pH of 12, where around 120 mg/l of silica is dissolved. It is evident that when the pH approaches the neutral pH level of 7, the silica dissolution exhibits the lowest recorded value at approximately 50 mg/l. It is obvious that as the pH enters the acidic range, there is a further increase until it reaches its peak at a pH of 3, accompanied by around 70 mg/l of dissolved silica.

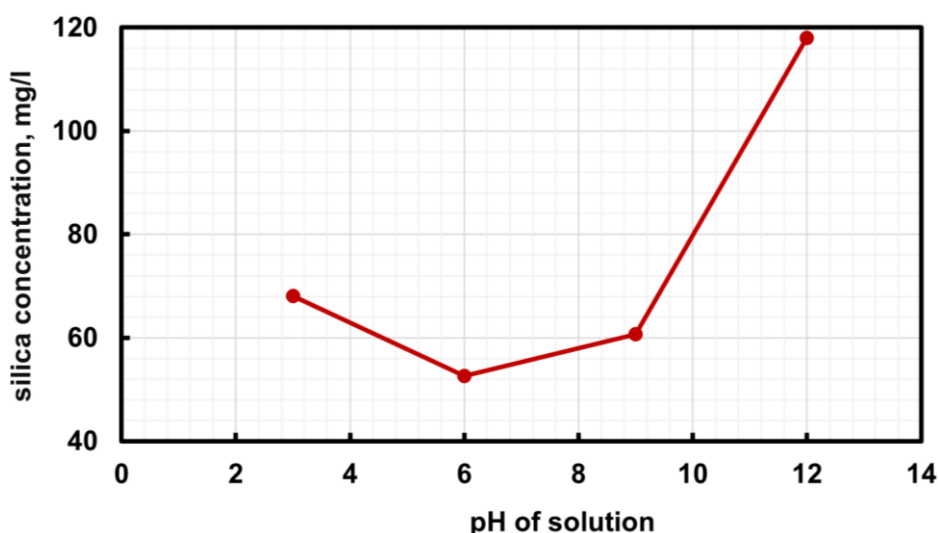


Fig. 4. Impact of changing PH solution on quartz hydrolysis (coarse particles) at ambient temperature

Transitioning to fine particles, as depicted in Figure 5. The graph exhibits a similar pattern to that of coarse particles, with a peak occurring at a pH of 12 and a concentration of approximately 180 mg/l. On the other hand, the lowest concentration is observed at a pH of 7, with a value of around 70 mg/l. It is noteworthy that silica dissolution is more significant in fine particles as opposed to coarse particles under identical pH conditions. The dissolution of silica in fine particles at a pH of 12 is measured to be 180 mg/l, whereas, for coarse particles at the same pH of 12, it is observed to be 120 mg/l. It is evident that the size of the particles significantly influences the hydrolysis process of quartz.

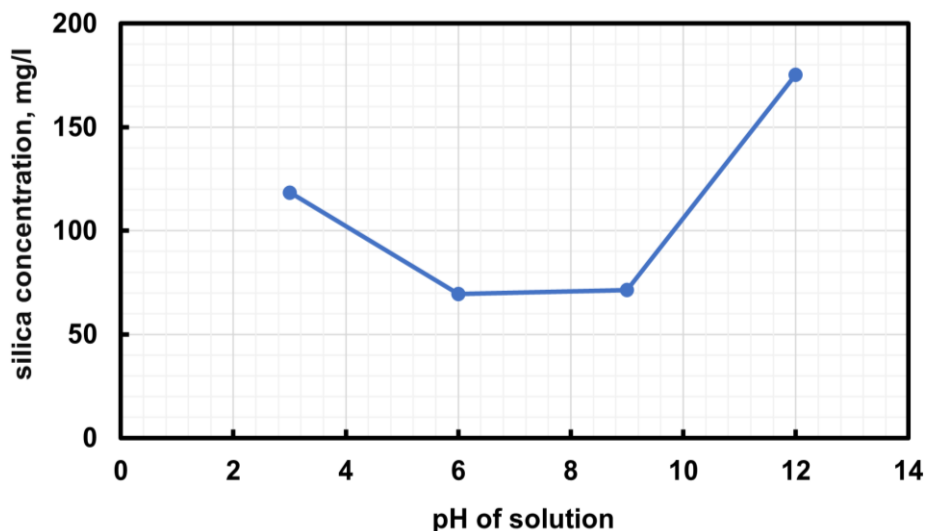


Fig. 5. Impact of changing pH solution on quartz hydrolysis (fine particles) at ambient temperature

3.4 The Impact of Brine on Quartz Hydrolysis

Salinity plays a vital role in chemical reactions. Hence, the salinity effect on silica dissolution (quartz hydrolysis) was studied [20,21]. The pure quartz was dissolved in different brine types (NaCl, MgCl₂, CaCl₂, and KCl) ranging from 0 to 800 ppm. Figure 6 shows silica dissolution, representing quartz hydrolysis in various brine solutions. The highest amount of silica dissolution was found in NaCl and KCl compared to CaCl₂, and MgCl₂ was the lowest at all concentrations. At 200 ppm, the silica dissolution recorded the highest value at KCl, followed by NaCl at around 50 and 45 mg/l silica dissolved, while MgCl₂ and CaCl₂ were the lowest, with silica dissolved at 32 and 34, respectively. Ali states that in chemical reactions. Divalent cations, specifically Mg²⁺ and Ca²⁺, exhibit the capacity to form complexes with reactor ions, decreasing or increasing the reaction process in the solution. The phenomenon can influence the silica dissolution rate and lower the reaction speed as divalent cations establish complexes with silica ions, reducing the amounts of silica dissolved [22].

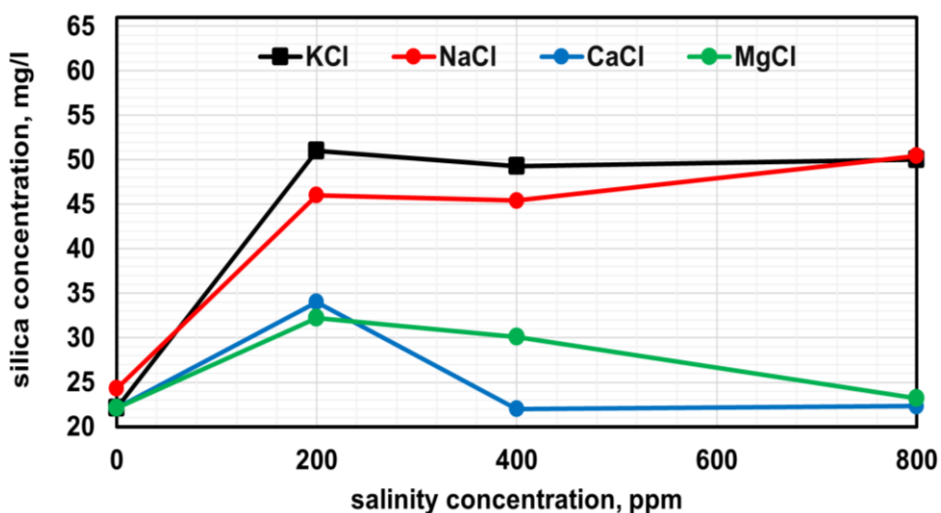


Fig. 6. Impact of salinity on quartz hydrolysis at ambient temperature

4. Conclusion

This study investigates quartz hydrolysis, which leads to silica dissolution in pure quartz, the predominant in sandstone formation; it also evaluates the effect of changing reservoir fluid parameters, namely brine composition and pH levels, on this reaction. Based on the analysis as mentioned earlier, it can be inferred the following:

- i. The time impact test showed that a time-dependent phenomenon demonstrates a positive correlation between reaction time and silica dissolution. This relationship persists until the reaction reaches a state of equilibrium, indicating that no more reactions occur beyond this point. The duration required for silica dissolution to reach equilibrium has been determined to be 60 hours.
- ii. The study observed the influence of pH on silica dissolution and found that the most significant amount of dissolution occurred at pH levels of 12 and 3. This finding suggests a notable escalation in silica dissolution under both high and low pH levels. The observed phenomenon can be ascribed to the impact of hydroxide ions (OH⁻) and hydrogen ions (H⁺) present in the solution, which serve as effective catalysts for the dissolving reaction.
- iii. The particle size analysis results indicate a positive correlation between particle size and quartz hydrolysis, with finer particles exhibiting greater dissolution values than coarser particles. To clarify, when the size of a quartz particle decreases, a more significant amount of silica will dissolve into the solution. This pertains to the measurement of surface area. When the particles are of reduced size, they exhibit an increased surface area, facilitating enhanced surface reactions.
- iv. In relation to the influence of salinity, it has been observed that NaCl and KCl exhibit the most pronounced effect on silica dissolution, whereas MgCl₂ and CaCl₂ demonstrate comparatively lower impact.

Acknowledgement

The authors would like to thank to Yayasan Universiti Teknologi PETRONAS (YUTP 015LC0-324) for funding this research. The authors would like to extend their gratitude to the Petroleum Engineering Department and Centre of Enhanced Oil Recovery for providing the resources and infrastructure.

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