The American Journal of Applied Sciences
ISSN 2689-0992 Volume 08 - 2026

Physicochemical Analysis of The Composition and Structural Characteristics of Sodium Silicate Solutions

Usmanova Madina
PhD Student, Bukhara State Technical University, Uzbekistan

Received: 04 Mar 2026 | Received Revised Version: 28 Mar 2026 | Accepted: 20 Apr 2026 | Published: 09 May 2026

Volume 08 Issue 05 2026 | Crossref DOI: 10.37547/tajas/Volume08Issue05-07

Abstract

This study analyzes the composition and structural characteristics of sodium silicate solutions (water glass). The influence of the SiO_2/Na_2O ratio (silicate modulus) on polymerization degree, structural organization, and stability is examined. It is shown that these solutions have a colloidal-polymeric nature, forming structures from simple units to complex networks.

The effects of pH, concentration, and temperature on structural changes and gelation processes are also considered. The results indicate that increasing the silicate modulus enhances polymerization, viscosity, and stability, which are important for industrial applications such as construction materials and adhesives.

Keywords: Sodium silicate, water glass, silicate modulus, SiO_2/Na_2O ratio, polymerization, colloidal structure, gelation, physicochemical properties.

Cite This Article: Usmanova Madina. (2026). Physicochemical Analysis of The Composition and Structural Characteristics of Sodium Silicate Solutions. The American Journal of Applied Sciences, 8(5), 30–33. https://doi.org/10.37547/tajas/Volume08Issue05-07

1. Introduction

Sodium silicate solutions, widely known as water glass, represent an important class of inorganic materials extensively used in modern industry and materials engineering. Their broad application in construction materials, adhesive systems, protective coatings, and composite technologies is due to their unique physicochemical properties, including high alkalinity, thermal resistance, and strong binding ability[1,2]. The functional performance of sodium silicate solutions is primarily governed by their chemical composition and structural organization. In particular, the SiO_2/Na_2O ratio, defined as the silicate modulus

$$M = \frac{SiO_2}{Na_2O}$$

plays a critical role in determining the degree of polymerization, viscosity, and stability of the system. An increase in this parameter leads to the formation of more complex silicate structures, transitioning from simple monomeric units to extended polymeric networks[3].

From a structural perspective, sodium silicate solutions exhibit a colloidal-polymeric nature, where silanol groups participate in condensation reactions forming siloxane bonds according to the following mechanism:

$$\text{Si–OH} + \text{HO–Si} \rightarrow \text{Si–O–Si} + H_2O$$

This process underlies the formation of three-dimensional network structures and governs key phenomena such as aggregation and gelation. The rate and extent of these transformations depend on physicochemical factors including pH, concentration, and temperature. In particular, a decrease in pH promotes gelation, while higher silicate modulus values contribute to increased viscosity and structural stability[4,5].

These relationships can be interpreted analytically through the dependence of viscosity and structural density on the silicate modulus, where higher values of Mcorrespond to increased intermolecular interactions and network connectivity[6]. Such structural evolution directly affects technological parameters, including setting time, mechanical strength, and adhesion performance.

Therefore, the purpose of this study is to analyze the composition and structural characteristics of sodium silicate solutions, as well as to evaluate the influence of key physicochemical parameters on their behavior and practical applications[7].

Experience and materials.

Sodium silicate solutions (water glass) with different silicate modulus values were used as the main object of study. The initial composition corresponded to the general formula Na_2 O·nSiO_2, where the silicate modulus

$$M = \frac{SiO_2}{Na_2O}$$

was varied in the range of 2.0–3.5 to investigate its effect on structural properties. Such variation made it possible to systematically evaluate the influence of composition on polymerization degree, viscosity, and stability of the system.

Distilled water was used as a solvent to adjust the concentration of the solutions, ensuring uniformity of experimental conditions. Hydrochloric acid (HCl) was applied to regulate the pH of the system and to initiate gelation processes. All reagents were of analytical grade and used without additional purification, which minimized the influence of impurities on the experimental results.

The experimental study was carried out in a sequential manner aimed at determining the relationship between composition and the structural characteristics of sodium silicate solutions. Initially, solutions with different silicate modulus values were prepared by controlled dilution and intensive mixing. Particular attention was paid to maintaining constant concentration conditions for all samples in order to ensure the comparability of the obtained data.

The silicate modulus for each sample was determined based on the ratio of silicon dioxide to sodium oxide content, and the chemical composition of the solutions was verified using standard analytical procedures. The pH of the prepared solutions was measured using a calibrated pH meter at a controlled temperature of 25 ± 1 °C. During the experiments, gradual acidification was performed, and pH changes were continuously monitored to study the kinetics of gelation.

The rheological properties of the solutions were evaluated by measuring viscosity using a rotational viscometer under constant temperature conditions. This allowed for the identification of the relationship between silicate modulus and internal structural organization of the system. Gelation processes were studied by controlled addition of acid to alkaline silicate solutions, during which the gel formation time and structural transformations were recorded. The dependence of gelation rate on pH and composition was subsequently analyzed.

The structural characteristics of sodium silicate solutions were assessed on the basis of indirect physicochemical indicators, including viscosity, gelation behavior, and stability of the colloidal system. The formation of polymeric silicate structures was interpreted in the context of classical models of silicate polymerization, where condensation reactions between silanol groups lead to the development of three-dimensional network structures.

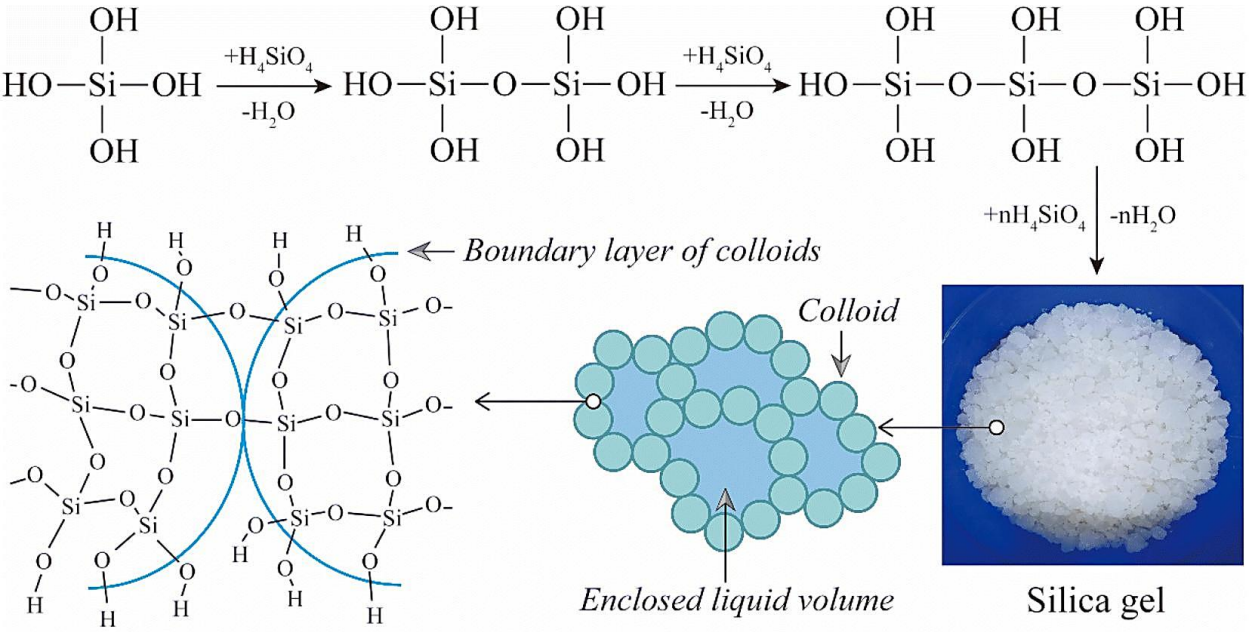

Figure 1. Structural evolution of sodium silicate solutions depending on silicate modulus

Figure 1. Schematic representation of structural transformation in sodium silicate solutions as a function of silicate modulus (M): (a) low-modulus solutions with predominantly monomeric and oligomeric silicate species; (b) intermediate structures with chain formation; (c) highly polymerized three-dimensional siloxane network at higher modulus values.

Table 1. Composition of sodium silicate solutions

Sample ID	SiO_2 (%)	Na_2O (%)	Silicate Modulus (M)	Concentration (%)
S1	26.5	13.2	2.0	30
S2	28.4	12.0	2.4	30
S3	30.1	11.0	2.7	30
S4	32.0	10.0	3.2	30
S5	34.5	9.5	3.5	30

Schematic representation of the structural evolution and polymerization mechanism in sodium silicate solutions. The figure illustrates the condensation of silicate monomers (H_4SiO_4), accompanied by water elimination (-H_2 O), leading to the formation of Si–O–Si bonds and the development of dimeric and polymeric chains. As the process continues, these chains interconnect to form a three-dimensional siloxane network structure.

In addition, the formation of colloidal particles is shown, including the presence of a boundary layer surrounding the particles and the encapsulation of liquid within the dispersed system. With increasing polymerization degree, the system undergoes gelation, resulting in the formation of silica gel as the final product.

Thus, the applied experimental methodology made it possible to comprehensively evaluate the influence of composition and physicochemical parameters on the structural evolution and functional properties of sodium silicate solutions.

2. Conclusion

This study investigated the composition and structural characteristics of sodium silicate solutions with varying

silicate modulus values. It was established that the SiO_2/Na_2O ratio plays a decisive role in determining the degree of polymerization, viscosity, and stability of the system. An increase in silicate modulus leads to the formation of more complex silicate structures, transitioning from monomeric units to highly polymerized three-dimensional networks.

The results confirmed that sodium silicate solutions exhibit a colloidal-polymeric nature, where structural transformations occur through condensation reactions forming Si–O–Si bonds. The influence of key physicochemical parameters, including pH, concentration, and temperature, was also identified as significant in controlling gelation processes and structural evolution. In particular, a decrease in pH accelerates gel formation, while higher modulus values enhance structural density and viscosity.

Overall, the findings provide a scientific basis for understanding the relationship between composition and structure in sodium silicate systems and offer practical insights for optimizing their application in construction materials, adhesives, and other industrial fields.

References

1. Iler, R. K. (1979). The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry. New York: John Wiley & Sons.
2. Greenberg, S. A. (1957). Studies on the colloidal behavior of silica in aqueous systems. The Journal of Physical Chemistry, 61(7), 960–965.
3. Sjöberg, S., & Ohman, L.-O. (1985). Equilibrium and structural studies of silicate solutions. Journal of Non-Crystalline Solids, 74(1–3), 103–114.
4. Alexander, G. B. (1953). The polymerization of silicic acid. Journal of the American Chemical Society, 75(22), 5655–5657.
5. Brinker, C. J., & Scherer, G. W. (1990). Sol–Gel Science: The Physics and Chemistry of Sol–Gel Processing. Boston: Academic Press.
6. Dove, P. M., De Yoreo, J. J., & Weiner, S. (2003). Biomineralization. Washington, DC: Mineralogical Society of America.
7. Bergna, H. E., & Roberts, W. O. (2006). Colloidal Silica: Fundamentals and Applications. Boca Raton: CRC Press.
8. Iller, R. K. (1975). Multivalent metal ions as catalysts for the polymerization of silicic acid. Journal of Colloid and Interface Science, 51(3), 388–394.