The Effect of Polymer Properties on the Rheological Behavior of Darbaza Clay-Based Suspensions

A Comparative Experimental Study on Molecular Weight, Composition, and Concentration Effects

Zhadyra Artykova
Department of Technology Inorganic and Petrochemistry Industries, M.Auezov South Kazakhstan University, Shymkent, Kazakhstan
articova@mail.ru (corresponding author)

Oral Beisenbayev
Department of Technology Inorganic and Petrochemistry Industries, M.Auezov South Kazakhstan University, Shymkent, Kazakhstan
oral-kb@mail.ru

Aziza Issa
Department of Technology Inorganic and Petrochemistry Industries, M.Auezov South Kazakhstan University, Shymkent, Kazakhstan
isa.aziza@mail.ru

Aigul Kydyraliyeva
Department of Technology Inorganic and Petrochemistry Industries, M.Auezov South Kazakhstan University, Shymkent, Kazakhstan
aigul.ukgu@mail.ru

Saltanat Yegemberdieva
Department of Technology Inorganic and Petrochemistry Industries, M.Auezov South Kazakhstan University, Shymkent, Kazakhstan
saltanat_2207@mail.ru

Received: 25 July 2025 | Revised: 12 September 2025 | Accepted: 27 September 2025

 DOI: https://doi.org/10.48084/etasr.13643

ABSTRACT

The rheological and filtration-technological characteristics of a 15% Darbaza clay-based suspension along with different dosages of newly synthesized SANVSK-series stabilizers were investigated in this study. Different techniques, such as rheological measurements, filtration tests, sedimentation stability analysis, Scanning Electron Microscopy (SEM), and Differential Thermal Analysis (DTA) were deployed. The results demonstrated that the use of SANVSK-2 as a stabilizer for Darbaza clay-based suspensions was optimal at a concentration of 0.5%. The polymer exhibited excellent thermal resistance (up to 180-200 °C) and salt resistance (up to 20% NaCl and 2% $CaCl_2$) maintaining its functional performance during harsh situations. The mechanistic analysis revealed that SANVSK-2 was able to protect the clay matrix against the adsorption of more water, and thus increase its stability by creating solvation layers. The strong presence of amide, imide, carboxylate, and sulfo functional contributed to the polymer's high resistance to electrolyte-induced destabilization and the reduction of the friction coefficient during drilling operations. Thus, it has been confirmed that SANVSK-2 is an excellent candidate for the application of a polymer additive that can withstand high temperature and salt for the low-clay and complicated drilling fluid systems.

Keywords-bentonite clay; electron microscopy; filtration-technological parameters; polyelectrolytes; salt resistance; stabilizers; thermal resistance

I. INTRODUCTION

Kazakhstan is one of the leading nations regarding the global oil and gas production with many strategic initiatives being implemented to strengthen this market. The country aims to expand the drilling operations to reach depths of 6,000 m and beyond. This challenge requires advanced drilling fluids that can maintain both the structural and functional performance under extreme conditions.

A lot of attention has been paid to the use of synthetic polymers, particularly acrylic polymers and their copolymers, due to their physicochemical properties. Specifically, the strong carbon-carbon bonds offer improved thermal and chemical stability when compared to traditional additives, such as Carboxymethylcellulose (CMC) and starch, which are susceptible to hydrolysis via ether and glycosidic linkages [1-4]. However, in deep reservoirs, where the environment is high saline, these polymers often lose their stabilizing capabilities, resulting in reduced rheological control and increased filtration loss. Furthermore, the majority of these materials are imported, leading to higher costs and reduced supply flexibility.

For all these reasons, local polymeric additives with improved thermal and salt resistance have been developed. It has been indicated that synthetic polymers including amide, carboxylate, sulfonate, and imide groups could provide enhanced performance under extreme drilling conditions [5-8]. The current research proposes a novel polymer reagent that is tailored to stabilize Darbaza clay-based drilling fluids. The synthesized reagent combined different functional groups to improve the adsorption to clay particles, promote suspension stability, and minimize filtrate loss in extreme environments.

Polymer composition plays a critical role in the rheological behavior of dispersed systems. For example, the increased molecular weight and concentration of polymeric additives can result in elevated viscosity promoting a non-Newtonian, shear-thinning behavior in particle suspensions [9-10]. In drilling fluid formulations, the addition of xanthan gum and polyanionic cellulose increases the consistency index while reducing the flow behavior index [11-12]. Similarly, the incorporation of Polyvinylpyrrolidone (PVP) into alumina suspensions has induced yield-pseudoplastic flow behavior by elevating the shear yield stress and altering the flow characteristics [13, 14]. In [15], the use of associative polymers in kaolin-based systems and coating colors enhanced their viscosity and viscoelastic properties through mechanisms, such as steric stabilization, polymer chain entanglement, and interparticle bridging.

However, these studies have focused on either model systems or polymers with limited thermal and salt tolerance [15-18]. The present study aims to fill this gap by evaluating the rheological behavior of Darbaza clay-based suspensions modified with newly synthesized SANVSK-series stabilizers, thereby contributing to the development of next-generation drilling fluid additives [9].

II. MATERIALS AND METHODS

A. Materials

In this study, acrylonitrile (CH_2CHCN, analytical grade) and sodium vinyl sulfonate (CH_2CHSO_3Na), both supplied by Sigma-Aldrich, were utilized. Fatty acids derived from gossypol resin were isolated from cottonseed oil production residues using standard saponification and acidification procedures. Sodium hydroxide (NaOH), sulfuric acid (H_2SO_4), formalin (37% aqueous formaldehyde solution), potassium persulfate ($K_2S_2O_8$), and sodium hydrogen sulfate ($NaHSO_4$) were employed without further purification.

B. Synthesis of the Composite Polymer Reagent

A series of copolymers were synthesized by changing the molar ratios of acrylonitrile to vinyl sulfonic acid in the range of 90:10 to 50:50. The polymerization reaction was carried out in an aqueous intermediate under controlled conditions using a redox initiator system. This structure consisted Potassium Persulfate (PP) and sodium hydrogen sulfate, enabling the reaction to proceed across a wide pH range of 2 to 12. In selected reactions, sodium hydroxide or sulfuric acid was added to adjust the degree of hydrolysis and the combination of the functional group. Additionally, fatty acids were introduced to improve functional performance.

The reactions were conducted in a flask with three openings equipped with a mechanical stirrer, reflux condenser, and nitrogen inlet, at 70 ± 2 ºC for 4 to 6 h. The resulting copolymers were sunk into acetone, filtered, washed, and dried under vacuum at 50 ºC for 24 h.

C. Preparation of Clay Suspensions

Montmorillonite-rich clay, found at Darbaza deposit in South Kazakhstan, was utilized to prepare clay suspensions. It was pre-dried, ground, and sieved through a 100 μm mesh. A high shear mixer (IKA T25 digital ULTRA-TURRAX) was used to disperse the clay in deionized water in order to derive aqueous suspensions with a solid content of 15% (w/w). This procedure lasted 30 min at 10,000 rpm, and then the composite polymer reagent was added in concentrations ranging from 0.1% to 1.0% by weight of the suspension.

D. Analytical Methods

To evaluate the physicochemical properties and performance of the modified clay suspensions, several techniques were applied. Particularly, a standard pycnometric method was utilized to measure the specific gravity, while a Baroid filter press determined the water yield (filtration rate) following the API 13B standards. The layer thickness and suction capacity were assessed using a filter cake profilometer and vacuum desiccator method, respectively. Regarding the rheological properties, including plastic viscosity, apparent viscosity, and static shear stress, a Fann 35 rotational viscometer at ambient and elevated temperatures (25 - 150 ºC) was employed.

Sedimentation tests took place over a 24-h period under static conditions to measure the stability, while DTA was performed using a Q-1500D instrument to characterize the thermal behavior. Aqueous dispersions containing 15% Darbaza clay and 0.5% polymer reagent were analyzed in a range of 25-500 ºC under nitrogen atmosphere. Microstructural analysis was conducted through SEM and JEOL, with clay suspension samples dried, sputtered with gold, and imaged to observe the morphological changes induced by polymer treatment.

All experiments were repeated three times to ensure reproducibility, and the mean values with standard deviations were reported.

III. RESULTS AND DISCUSSION

A model system consisting of 15% clay from the Darbaza deposit and different concentrations of the synthesized composite polymer reagent was used to investigate the polymer's effect on the rheological and filtration-technological parameters.

Table I summarizes these parameter values for varying polymer concentrations. At low percentages, the addition of reagent resulted in pronounced flocculation behavior, due to increases in performance indicators. For example, at a polymer concentration of 0.10%, viscosity reached 11.0 s, the 24-h sedimentation was recorded at 11.0%, the static shear stress values were 40.3 and 42.0 Pa after 1 and 10 min, respectively, and the filtrate loss measured 40 ml. A partial hydrophobization of clay particle surfaces due to the adsorption of polyelectrolyte chains could explain these values. As the polymer concentration increased, the viscosity values raised, while both the water yield and sedimentation rate decreased. Consequently, the suspension became less thixotropic, and a moderate thinning of the system occurred.

The optimal performance was achieved at 0.5% polymer concentration, where viscosity reached 14.0 s, the 24-h sedimentation decreased to 1.0%, and static shear stress exhibited 43.6 and 47.4 Pa after 1 and 10 min, respectively. The fluid loss was minimized to 5 ml, indicating excellent filtration control. This performance can be attributed to the formation of an adsorption-solvation layer on the clay particle surfaces. This layer prevents compact particle coagulation while promoting the formation of floccules and polymer chains. Additionally, the supramolecular interactions between polymer and clay particles lead to an enhanced suspension viscosity and long-term stability under static conditions.

Similar results have been detected. For instance, authors in [16] demonstrated that intercalated polyacrylamide/clay nanocomposites enhanced the thermal and salt resistance in dispersed systems, while improved rheological performance of attapulgite suspensions under extreme conditions was reported in [17]. These observations revealed that multifunctional SANVSK-type stabilizers could catch high rheological stability even under harsh conditions (up to 200 °C and high ionic strength).

Additionally, the observed shear-thinning and thixotropic properties in Darbaza clay suspensions were consistent with the effects in [18], although the SANVSK-series achieved comparable performance at lower concentrations and in region-specific clay systems. Thus, the experimental results confirmed that the synthesized composite polymer reagent functions as an effective rheology modifier and stabilizer for Darbaza clay-based suspensions [19].

TABLE I. FILTRATION AND RHEOLOGICAL PARAMETERS OF 15% DARBAZA CLAY SUSPENSION VERSUS POLYMER CONCENTRATION

Polymer concentration (%)		-	0.05	0.10	0.25	0.5	0.75	1
Conditional viscosity, T^{200}_{100} (s)		4.5	7.5	11.0	13.5	14.0	22.5	28
Density ($\times 10^3$ kg/m^3)		1.27	1.27	1.27	1.26	1.26	1.25	1.2
24-h Sedimentation (%)		4.0	12.0	11.0	6.0	1.0	0.0	0.0
Water yield (ml)		33	40	40	17.0	5.0	4.0	3.0
Layer thickness (mm)		4.0	6.0	5.0	2.0	1.0	1.0	0.5
Static shear stress (Pa)	**1 min**	37.4	53.4	40.3	41.8	43.6	50.5	74.8
	10 min	39.2	54.2	42.0	43.4	47.4	51.4	77.3
pH		6.8	7.6	8.0	8.6	8.8	9.0	9.0

To assess salt resistance, various concentrations of sodium chloride (0.5% - 20%) and calcium chloride (0.5% - 2%) were added to stabilized suspensions. The evaluation was based on the changes in filtration characteristics and rheological parameters (Table II). The added NaCl, both at low and high concentrations, caused minimal increases in water loss, while the layer thickness remained within acceptable limits (1.5-2.0 mm).

The results suggested that the system maintained its structural and mechanical performance despite the addition of both monovalent and divalent salts. This can be explained due to the presence of polar sulf and imide groups within the polymer backbone. These groups probably interact with the active sites of clay surfaces, leading to the formation of adsorption layers that establish a high-energy barrier against electrolyte-induced coagulation. The steric and electrostatic stabilization mechanisms, thus, counteract the destabilizing effects of Na^+ and Ca^{2+} ions, supporting long-term suspension stability.

Further examination of the thermal resistance occurred based on simulated conditions on 15% Darbaza clay suspensions containing 0.5% polymer reagent. A laboratory autoclave was utilized at a range of 200-220 °C and 10-20 atm over a 6-h period. Table III presents the post-treatment evaluation in which the essential rheological and filtration properties were preserved, confirming that in high temperature environments, the reagent is suitable for use.

The introduction of the composite polymer reagent at a concentration of 0.5% led to a marked increase in the effective viscosity of the clay suspension. This value promoted the formation of a self-supporting 3-D structure, enhancing the system's resistance to deformation and improving the efficiency of cuttings' transport during drilling operations. However, the increased structural resistance also implied a higher energy demand to overcome the internal friction of the suspension, which should be considered when optimizing the flow parameters in field applications.

TABLE II. EFFECT OF ELECTROLYTES AND TEMPERATURE ON TREATED 15% DARBAZA CLAY SUSPENSION (0.5% POLYMER)

Reagent composition (%)	NaCl	-	10	20	-	-	-
	$CaCl_2$	-	-	-	1.0	2.0	-
Temperature (°C)			-	-	-	-	-
Conditional viscosity, $T^{200}{}_{100}$ (s)		14.0	20.2	21.0	24.7	29.0	20.0
Density (× 10^3 kg/m^3)		1.26	1.31	1.32	1.27	1.28	1.28
Water yield (ml)		4.0	7.0	8.5	6.0	7.0	8.0
Layer thickness (mm)		1.0	1.5	1.5	1.5	2.0	1.0
Static shear stress (Pa)	43.6	56.2	58.5	68.7	73.8	63.8	
	47.4	66.7	72.8	72.4	85.6	62.9	

TABLE III. PROPERTIES OF SANVSK-2 MODIFIED CLAY SUSPENSION BEFORE AND AFTER HYDROTHERMAL TREATMENT

Temperature (°C)	**Desnity (× 10^3 kg/m^3)**	**Water yield (ml)**	**Layer thickness (mm)**	**pH**	**24-h sedimentation (%)**	**Stability, (kg/m^3)**	**Viscosity, $T^{200}{}_{100}$ (s)**	**Static shear stress (Pa)**	
								1 min	**10 min**
Without additives									
25	1.35	32.5	4.0	6.5	5.0	0.07	25.0	32.4	43.2
220	1.30	40.0	6.0	6.0	10.5	0.12	36.4	-	-
Water-soluble polymers based on hydrolyzed polyacrylonitrile in the presence of a mixture of sodium hydroxide and sulfuric acid (C = 0.5%)									
25	1.30	5.0	0.5	8.5	0	0.02	74.3	142.1	155.5
220	1.30	5.5	0.5	8.5	0	0.02	21.0	15.0	17.5

At high temperatures, the polymer-modified suspension exhibited greater viscosity compared to untreated or conventionally stabilized systems at ambient conditions. However, due to thermal softening and increased molecular mobility, the system demonstrated enhanced flowability, as reflected by a moderate decrease in apparent viscosity under thermal loading. This temperature-responsive rheological behavior suggests that the polymer contributes to both high-temperature structural integrity and controlled mobility.

Despite thermal exposure, the fluid loss, layer thickness, and daily sedimentation remained stable, showing minimal deviation from the values recorded under ambient conditions. This indicates that the surface-modifying action of the polyelectrolyte contributed to the thermal protection of clay particles and prevented undesirable structural breakdown. Changes in shear stress values further support that the composite polymer reagent enhanced the thixotropic properties of the suspension at lower temperatures, contributing to structural recovery after shear and sedimentation suppression during downtime.

The thermal stability of the developed polymer reagent was recognized as a key performance determinant for its application in high-temperature drilling environments. To assess this property, Thermogravimetric Analysis (TGA) was conducted using a TGA/DSC1 system (Mettler Toledo) under a nitrogen atmosphere, with a heating rate of 5 °C/min in the temperature range of 25 – 860 °C (Figure 1). The TGA curve of the 15% Darbaza clay dispersion with 0.5% polymer reagent exhibited a distinct endothermic peak between 70 °C and 220 °C, associated with the evaporation of physically adsorbed and interlayer-bound moisture. A second endothermic event at 400 °C corresponded to polymorphic transitions in silicate and aluminosilicate mineral phases. In the range of 280-350 °C, broad exothermic effects were observed, due to the oxidation and combustion of organic fragments and volatile functional groups within the polymer structure, accounting for a 56% mass loss between 220 °C and 770 °C.

At higher temperatures (> 450 °C), minor exothermic transitions were detected, indicating the decomposition of sulfur-containing groups, with an additional 12% weight loss between 770 °C and 860 °C. These results confirmed that the composite polymer reagent maintained thermal stability up to 220–250 °C, with gradual decomposition at higher temperatures, which is typical for polymers containing sulfonic, amide, and imide functionalities.

Fig. 1. DTA of Darbaza clay suspension with 0.5% polymer reagent.

The DTA results were in good agreement with the findings obtained from the hydrothermal stability tests (15% Darbaza clay suspensions treated with 0.5% of the synthesized composite polymer reagent).

An integrated analysis was conducted in order to understand the interactions between the composite polymer reagent and the clay matrix. This involved both filtration-technological assessments and electron microscopy, with the main focus placed on the variations in polymer concentration (Table I, Figures 2 and 3). This approach enabled the correlation of macroscopic rheological behavior with nanoscale and microscale structural modifications within the suspension.

Microstructural investigations were performed on 15% aqueous dispersions of bentonite clay from the Darbaza deposit, treated with SANVSK-2 stabilizer in concentrations ranging from 0.01% to 1.0%. The SEM images revealed that at low concentrations (0.01% - 0.25%), the stabilizer caused pronounced flocculation, as seen by the formation of large, compact aggregates. These masses resulted from the coagulation of hydrophobized clay particles, which occurred upon partial adsorption of polyelectrolyte chains. This led to a significant increase in filtration-technological parameters, as illustrated in Figure 2.

(a) (b) (c)

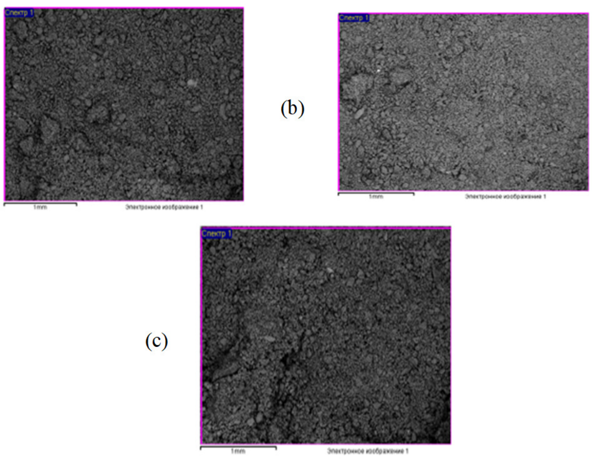

Fig. 2. Microstructure of Darbaza clay suspension with SANVSK-2 at: (a) 0.01%, (b) 0.1%, and (c) 0.25%.

Heterogeneous structures composed of crystalline and amorphous phases were observed, which is characteristic of magnesium aluminosilicate frameworks with disordered surface morphology. The presence of amorphous areas suggested partial encapsulation of clay particles by polymeric layers, contributing to changes in interparticle interactions and the onset of coagulative behavior. With increasing concentration of the SANVSK-2 reagent (≥0.5%), the microstructure transitioned from compact flocs to a more dispersed, layered architecture, indicating the formation of adsorption-solvation layers that enhance system stability and prevent particle aggregation. This correlated with observed decreases in sedimentation and filtrate loss, and a rise in effective viscosity as the system shifted from a flocculated to a structured, thixotropic regime (Figure 3).

These findings supported that the aggregation and stabilization behavior of Darbaza clay suspensions in the presence of the composite polymer reagent depend on concentration. At low dosages, hydrophobization and bridging flocculation dominated, while at optimal concentrations (~ 0.5%), the formation of continuous polymer-clay networks and hydration shells ensured colloidal stability, improved the rheological performance, and resistance to external thermal and ionic influences.

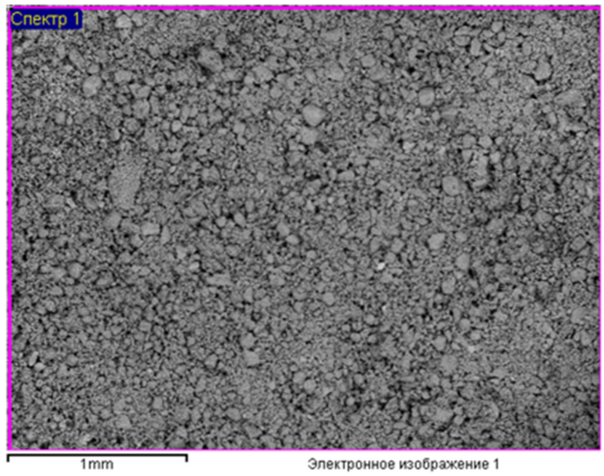

Fig. 3. Microstructure and mineral composition of Darbaza clay suspension with 0.5% polymer reagent.

Further increases in the concentration of the composite polymer reagent SANVSK-2 to 0.5% and 1.0% led to significant changes in the internal structure of the clay-polymer system. As observed in Table I and Figure 3, the system evolves from loosely aggregated flocs to a denser and ordered supramolecular network, formed through the intensified interactions between the functional groups of the polyelectrolyte (amide, imide, sulfo, and carboxylate) and magnesium-aluminosilicate minerals inherent to the Darbaza clay.

In rheological terms, this structural reorganization led to a reduction in key technological parameters, such as sedimentation, fluid loss, and filter cake thickness, confirming the stabilizing effect of the polymer. However, due to the viscous nature of the polyelectrolyte, the system exhibited an increase in apparent viscosity, accompanied by a reduction in shear strength, which is a characteristic of a plasticization effect.

The formation of such supramolecular structures was strongly dependent on the high polarity and associativity of the polymer's functional groups. The volumetric effects of macromolecular coils in the solution resulted in the development of intermolecular polymer-clay associations, enhancing the steric stabilization and dispersion homogeneity. At a concentration of 0.5% SANVSK-2, the system reached a thermodynamically stable state, with rheological and filtration-technological parameters that complied with the operational criteria for low-solid-phase thixotropic drilling fluids, suitable for small-diameter well drilling.

IV. CONCLUSION

This research examined clay suspensions collected from the Darbaza deposit focusing on their rheological and filtration-technological behavior using new polyfunctional polymer stabilizers of the SANVSK series. The results of all laboratory tests exhibited excellent salt and thermal resistance. In systems with up to 20% NaCl and 2% $CaCl_2$, low filtration rates, stable sedimentation profiles, and rheological performance were noted. Autoclave testing at 180-200 °C and Thermogravimetric Analysis (TGA) confirmed the thermal stability of the polymer-clay systems. The mechanistic investigation of SANVSK-2 revealed a concentration-dependent interaction pathway. At higher concentrations, adsorption-solvation layers formed on the clay particle surfaces and contributed to improved colloidal stability, preventing coagulation and promoting spatial network formation.

Overall, the SANVSK polymer series can be considered as effective, thermally and chemically stable stabilizers for low-clay drilling fluids, particularly suited for deep well operations and high-salinity environments. These findings provide a scientific basis for the industrial implementation of SANVSK reagents in modern drilling fluid technologies.

FUNDING

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No.AP14972915).

REFERENCES

[1] S. Ghaderi, A. Ramazani S.A., and S. A. Haddadi, "Applications of highly salt and highly temperature resistance terpolymer of acrylamide/styrene/maleic anhydride monomers as a rheological modifier: Rheological and corrosion protection properties studies," *Journal of Molecular Liquids*, vol. 294, Nov. 2019, Art. no. 111635, https://doi.org/10.1016/j.molliq.2019.111635.

[2] N. Mohammedi, F. Zoukrami, and N. Haddaoui, "Preparation of Polypropylene/Bentonite Composites of Enhanced Thermal and Mechanical Properties using L-leucine and Stearic Acid as Coupling Agents," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7207–7216, June 2021, https://doi.org/10.48084/etasr.4148.

[3] V. F. Kurenkov, A. K. Vagapova, and V. A. Myagchenkov, "The effect of nature of cation on the radical polymerizations of calcium, strontium and barium salts of P-styrenesulphonic acid in aqueous solutions," *European Polymer Journal*, vol. 18, no. 9, pp. 763–767, 1982, https://doi.org/10.1016/0014-3057(82)90142-2.

[4] F. Kamali, R. Saboori, and S. Sabbaghi, "Fe3O4-CMC nanocomposite performance evaluation as rheology modifier and fluid loss control characteristic additives in water-based drilling fluid," *Journal of Petroleum Science and Engineering*, vol. 205, Oct. 2021, Art. no. 108912, https://doi.org/10.1016/j.petrol.2021.108912.

[5] Moradi S.s.t., N. I. Nikolaev, I. V. Chudinova, and A. S. Martel, "Geomechanical study of well stability in high-pressure, high-temperature conditions," *Geomechanics and Engineering*, vol. 16, no. 3, pp. 331–339, 2018, https://doi.org/10.12989/gae.2018.16.3.331.

[6] S. Davoodi, A. Ramazani S.A, A. Soleimanian, and A. Fellah Jahromi, "Application of a novel acrylamide copolymer containing highly hydrophobic comonomer as filtration control and rheology modifier additive in water-based drilling mud," *Journal of Petroleum Science and Engineering*, vol. 180, pp. 747–755, Sept. 2019, https://doi.org/10.1016/j.petrol.2019.04.069.

[7] K. Lv, H. Du, J. Sun, X. Huang, and H. Shen, "A Thermal-Responsive Zwitterionic Polymer Gel as a Filtrate Reducer for Water-Based Drilling Fluids," *Gels*, vol. 8, no. 12, 2022, Art. no. 832, https://doi.org/10.3390/gels8120832.

[8] J. Li, J. Sun, K. Lv, Y. Ji, J. Ji, and J. Liu, "Nano-Modified Polymer Gels as Temperature- and Salt-Resistant Fluid-Loss Additive for Water-Based Drilling Fluids," *Gels*, vol. 8, no. 9, Aug. 2022, Art. no. 547, https://doi.org/10.3390/gels8090547.

[9] Z. Artykova, O. Beisenbayev, A. Issa, and A. Kydyraliyeva, "Modification of polymers to synthesize thermo-salt-resistant stabilizers of drilling fluids," *Open Engineering*, vol. 15, no. 1, Jan. 2025, https://doi.org/10.1515/eng-2024-0097.

[10] E. Merz, T. Alfrey, and G. Goldfinger, "Intramolecular reactions in vinyl polymers as a means of investigation of the propagation step," *Journal of Polymer Science*, vol. 1, no. 2, pp. 75–82, Mar. 1946, https://doi.org/10.1002/pol.1946.120010202.

[11] V. P. Barabanov, S. V. Krupin, and D. S. Zagidullina, "Determination of the composition of powdered hydrolyzed polyacrylonitrile," *Interuniversity Collection of Chemical Technology: Organoelement Compounds and Polymers*, vol. 6, pp. 55–9, 2017.

[12] T. Liu *et al.*, "Influence of Polymer Reagents in the Drilling Fluids on the Efficiency of Deviated and Horizontal Wells Drilling," *Energies*, vol. 13, no. 18, Sept. 2020, Art. no. 4704, https://doi.org/10.3390/en13184704.

[13] O. K. Beysenbayev, A. S. Tleuov, B. M. Smailov, and B. S. Zakirov, " Obtaining and research of physical and chemical properties of chelated polymer-containing microfertilizers on the basis of technogenic waste for rice seed biofortification," *NEWS of National Academy of Sciences of the Republic of Kazakhstan,* vol. 1, no. 433, pp. 80-89, Feb. 2019, https://doi.org/10.32014/2019.2518-170X.10.

[14] A. R. Ismail, A. Aftab, Z. H. Ibupoto, and N. Zolkifile, "The novel approach for the enhancement of rheological properties of water-based drilling fluids by using multi-walled carbon nanotube, nanosilica and glass beads," *Journal of Petroleum Science and Engineering*, vol. 139, pp. 264–275, Mar. 2016, https://doi.org/10.1016/j.petrol.2016.01.036.

[15] J. Xu, Z. Qiu, X. Zhao, and W. Huang, "Hydrophobic modified polymer based silica nanocomposite for improving shale stability in water-based drilling fluids," *Journal of Petroleum Science and Engineering*, vol. 153, pp. 325–330, May 2017, https://doi.org/10.1016/j.petrol.2017.04.013.

[16] S. Zhang *et al.*, "Synthesis and Characterization of an Novel Intercalated Polyacrylamide/Clay Nanocomposite," *Gels*, vol. 9, no. 2, Jan. 2023, Art. no. 104, https://doi.org/10.3390/gels9020104.

[17] W. Zheng, S. Wang, L. Bai, and C. Yang, "Investigation of high temperature rheological properties for attapulgite suspensions," *Scientific Reports*, vol. 15, no. 1, Aug. 2025, Art. no. 28084, https://doi.org/10.1038/s41598-025-11219-z.

[18] B. A. Hamad *et al.*, "A Novel Amphoteric Polymer as a Rheology Enhancer and Fluid-Loss Control Agent for Water-Based Drilling Muds at Elevated Temperatures," *ACS Omega*, vol. 5, no. 15, pp. 8483–8495, Apr. 2020, https://doi.org/10.1021/acsomega.9b03774.

[19] Z. K. Artykova, O. K. Beisenbayev, A. A. Kadyrov, S. A. Sakibayeva, and B. M. Smailov, "Synthesis and preparation polyacrylonitrile and vinyl sulfonic acid in the presence of gossypol resin for drilling fluids," *Rasayan Journal of Chemistry*, vol. 16, no. 4, Oct. 2023, Art. no. 2313, https://doi.org/10.31788/RJC.2023.1618497.