

SYNTHESIS OF VARIOUS TRANSITION METAL SALTS OF NATURAL PETROLEUM ACIDS AND THEIR INVESTIGATION AS ANTISTATIC ADDITIVES FOR DIESEL DISTILLATE

Ulvi Muradov, Elgun Hasanov, Rufana Alizadeh, Vugar Gasimov,
Vusala Guliyeva

*Institute of Petrochemical Processes named after acad. Y. Mammadaliyev,
Baku, Azerbaijan*

Received: 01 February 2026

Accepted: 10 April 2026

Published: 13 April 2026

This study investigates the synthesis of various transition metal salts based on natural petroleum acid and their performance as antistatic additives in diesel distillate. Since electrostatic charging of petroleum products poses fire and explosion hazards, increasing fuel electrical conductivity is essential for safe charge dissipation. Metal–organic compounds are therefore considered effective antistatic agents.

Cobalt, manganese, nickel, zinc, and copper salts of natural petroleum acid were synthesized via a neutralization reaction. The reaction products were separated, the solvent was removed by distillation, and the corresponding metal soaps were obtained. The structures of the synthesized compounds were confirmed by IR spectroscopy.

The metal salts were added to diesel distillate at concentrations of 0.05%, 0.1%, and 0.15%. Electrical conductivity was measured using an EL-4M conductivity meter in accordance with relevant standards. Untreated diesel fuel exhibited conductivity values of 72–77 pS/m.

The addition of the metal salts significantly increased electrical conductivity. Nickel and zinc salts showed the highest efficiency, with the nickel salt at 0.15% raising conductivity to 1850 pS/m. These results indicate that metal salts of natural petroleum acid, particularly the nickel salt, are promising antistatic additives with potential for industrial application in improving the safety of diesel fuel storage and transportation

Keywords: natural petroleum acid; transition metal salts; antistatic additives; diesel distillate

INTRODUCTION

The electrostatic charge of crude oil and petroleum products not only poses an explosion and fire risk, but it also considerably impedes the effective and safe execution of different technological procedures throughout the fuel handling chain. Frictional interactions between the liquid hydrocarbon phase and solid surfaces result in electrostatic charges during pumping, mixing, filtering, loading, unloading, and pipeline transit. If these charges are not efficiently dissipated, they can accumulate to critical levels, resulting in spark discharge and the ignition of combustible vapors. As a result, preventing static electricity accumulation is regarded as one of the petroleum industry's top safety issues. In practice, a wide range of preventive measures have been devised and deployed, including basic grounding systems,

sophisticated electrostatic monitoring devices, and integrated engineering safety solutions. Grounding is one of the simplest, most dependable, and extensively used strategies for minimizing the electrification of liquid dielectrics. Proper grounding guarantees that externally generated charges are safely discharged to the earth potential, thus preventing dangerous electrostatic discharges.[3].

When selecting a fuel additive, it is critical to examine the fuel's hydrocarbon content and physicochemical properties. The efficiency of any additive is heavily influenced by factors such as aromatic content, polarity, sulfur concentration, and trace contaminants. For example, in gasoline with a low aromatic concentration, metal-containing antidetonation additives frequently function better due to changes in solubility and dispersion behavior. At the same time, when anti-crystallization additives are put into fuels, even tiny amounts of water in the system can have an unfavorable effect on fuel quality and additive performance. Under these conditions, the additive may preferentially dissolve in the aqueous phase, reducing its effective concentration in the hydrocarbon medium. This reduces functional efficiency and inhibits the addition from attaining the desired technical impact. Therefore, compatibility between the additive and the fuel matrix must be thoroughly examined, particularly in terms of moisture sensitivity and phase stability [4-6].

Antistatic additives are specifically employed to prevent the accumulation of static electricity during fuel transportation, storage, and loading operations. In particular, during the high-speed transfer of light fuels—such as diesel and jet fuel—into storage tanks, tank trucks, or aircraft fuel systems, intense electrokinetic processes take place. The rapid movement of low-conductivity hydrocarbons through pipelines and filters promotes charge separation at phase boundaries and contact surfaces. As a result, a double electric layer is formed between the metallic surface and the moving upper layer of the fuel. Charge creation increases dramatically as flow velocity and turbulence increase. Because hydrocarbon fuels have a limited electrical conductivity, these charges do not dissipate quickly and instead build to hazardous amounts. When the electrostatic potential difference surpasses a critical threshold, spark discharge may occur, posing a significant risk of igniting and explosion [7-9]. The accumulation process is considerably more significant in closed systems or low-humidity environments, when natural charge dissipation methods are limited. As a result, maintaining controlled electrical conductivity within acceptable operational limits is critical to avoiding electrostatic mishaps [10-11].

In order to dissipate static energy from the system effectively, it is necessary to increase the electrical conductivity of the fuel so that generated charges can be rapidly neutralized and safely discharged. For this purpose, metal-organic compounds are considered among the most efficient antistatic additives. These compounds typically contain polar functional groups capable of promoting charge mobility in otherwise nonpolar hydrocarbon media. Even extremely small concentrations of such additives can lead to substantial improvements in conductivity. For instance, the addition of approximately 0.00006% of certain chromium salts of dialkylsalicylic acid has been shown to increase electrical conductivity from 0.2–20 pS/m to 100–200 pS/m, approaching internationally accepted safety thresholds for static charge dissipation. This demonstrates the high efficiency of metal-containing organic additives in enhancing the electrostatic stability of fuels without significantly altering their primary physicochemical properties [12–15].

Currently, various industrial antistatic additives are commonly utilized in commercial fuel systems, including Shell ASA-3, Sigbol, ACP-3, and others. These formulas are intended to increase charge relaxation while remaining compatible with engine systems and fuel standards. In addition to these commercial products, a variety of organic salts and coordination complexes have been proposed and studied as potential antistatics. Chromium-based compounds, in particular, frequently display significantly higher conductivity-enhancing qualities due to their advantageous coordination features and ionic behavior. However, despite their efficiency, the incorporation of metal- and nitrogen-containing compounds into fuel formulations may present certain operational challenges. During combustion, these elements can contribute to the formation of metal oxide residues and deposits on internal engine components, which may negatively affect long-term engine performance and

maintenance requirements. Therefore, while metal–organic additives provide substantial antistatic benefits, their formulation must be carefully optimized to balance electrostatic performance with combustion cleanliness and operational reliability [18–20].

EXPERIMENTAL

At present, the problem of electrostatic charging of fuels and solvent mixtures is considered one of the most pressing issues in the petrochemical industry, particularly in processes involving storage, pumping, mixing, and transportation of light petroleum fractions. Numerous scientific investigations have demonstrated that the introduction of specifically designed antistatic additives into crude oil and petroleum products represents one of the most effective and technologically feasible approaches to mitigating electrostatic hazards. In this context, extensive and systematic research has been conducted at the Y.H. Mammadaliyev Institute of Petrochemical Processes, where the synthesis, characterization, and evaluation of metal–organic compounds derived from natural petroleum acids have been carried out under controlled laboratory conditions. The experimental work was aimed at developing efficient antistatic systems capable of significantly increasing the electrical conductivity of diesel distillate while maintaining compatibility with the fuel matrix.

Within the framework of the present study, cobalt (Co), manganese (Mn), nickel (Ni), zinc (Zn), and copper (Cu) salts of palmitic acid were synthesized and subsequently evaluated. The synthesis procedure was based on a neutralization reaction between palmitic acid and the corresponding metal-containing reagent. Initially, a 35–40% aqueous sodium hydroxide (NaOH) solution was gradually added to palmitic acid under continuous stirring in order to initiate the neutralization process and form the intermediate sodium salt. The reaction mixture was maintained at a controlled temperature of 50–60°C for approximately 30 minutes to ensure complete interaction between the acid and the alkaline solution and to promote homogeneous reaction conditions.

Following the neutralization stage, hexane was introduced into the reaction flask as an organic solvent in the required volume. The purpose of the solvent addition was to create a suitable medium for subsequent ion–exchange interaction and to facilitate phase separation. The reaction mixture was thoroughly stirred to ensure uniform dispersion of the components. Thereafter, the corresponding metal salt (Co, Mn, Ni, Zn, or Cu) was added portionwise to the reaction medium, either in dry solid form or as a prepared solution, depending on its solubility characteristics. The addition was performed gradually to avoid localized concentration gradients and to maintain reaction stability. Continuous stirring was maintained for approximately 3 hours to ensure complete conversion and formation of the target metal carboxylates.

Upon completion of the reaction, the mixture was transferred to a separatory funnel, allowing sufficient time for phase separation to occur. The lower aqueous phase was carefully removed, while the upper organic layer containing the synthesized metal salt was retained. The organic phase was subsequently transferred to a distillation flask, and the solvent was removed under controlled conditions by distillation. This step resulted in the isolation of the corresponding metal salts of palmitic acid in solid or semi-solid form, depending on the nature of the metal ion.

The obtained metal salts were then subjected to further experimental evaluation to determine their antistatic properties. For this purpose, the synthesized compounds were incorporated into diesel distillate at predetermined concentrations of 0.05%, 0.1%, and 0.15% by weight. The additives were carefully mixed with the diesel fuel to ensure uniform distribution throughout the liquid phase. Electrical conductivity measurements were subsequently carried out using an EL-4M conductivity meter under standardized laboratory conditions. All measurements were performed in accordance with the requirements of GOST 25950-83 and GOST 33461-2015 standards to ensure reliability, reproducibility, and compliance with established methodological procedures.

Through this systematic experimental approach, the synthesized transition metal salts of natural petroleum acids were obtained in reproducible form and prepared for detailed

investigation of their influence on the electrical conductivity and antistatic behavior of diesel distillate.

RESULTS AND DISCUSSION

For this purpose, a series of laboratory-scale experimental studies were conducted. Specifically, various metal salts (Co, Mn, Ni, Zn, and Cu) of natural petroleum acid were synthesized. As a representative example, the IR spectrum of the synthesized nickel salt is shown in Figure 1. The obtained metal salts were incorporated into diesel fuel as antistatic additives at different concentrations (0.05%, 0.1%, and 0.15%), and their effect on the electrical conductivity of the diesel fuel was systematically investigated.

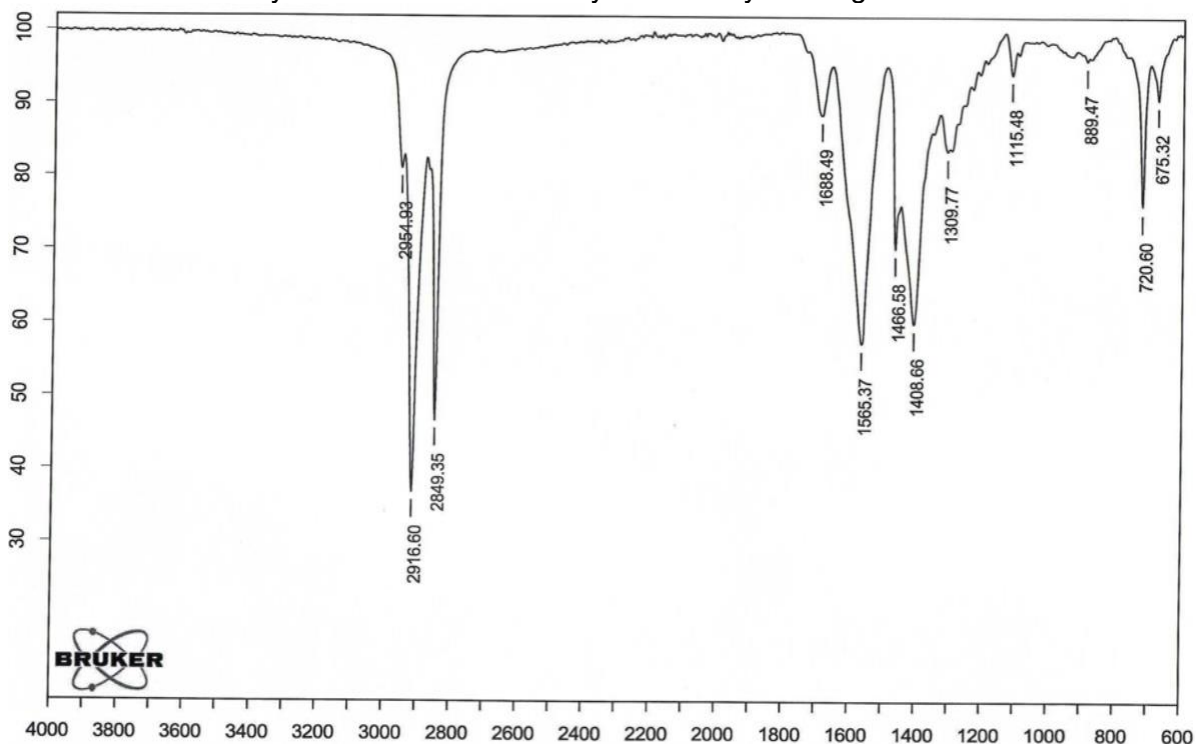


Figure 1 IR spectrum of the synthesized Ni metal salt of palmitic acid

The IR spectrum of the sample exhibits the following absorption bands: deformation vibrations at 720 and 1466 cm^{-1} and stretching vibrations at 2849, 2916, and 2954 cm^{-1} corresponding to C–H bonds of CH and CH₂ groups. Additionally, stretching vibrations of the COO⁻ groups are observed at 1408 and 1565 cm^{-1} (bands of medium intensity).

The changes in electrical conductivity of the diesel distillate upon the addition of antistatic additives were measured using an EL-4M conductivity meter. The measurements were carried out in accordance with the requirements of GOST 25950-83 and GOST 33461-2015 standards.

Table 1 The addition of cobalt (Co), manganese (Mn), nickel (Ni), zinc (Zn), and copper (Cu) salts of natural petroleum acid to diesel distillate at concentrations of 0.05%, 0.1%, and 0.15% resulted in changes in the electrical conductivity of the diesel fuel

Sample Name	Additive Concentration, %	Electrical conductivity Psm/m				
		After 1 Day	After 10 Day	After 20 Day	After 30 Day	After 40 Day
	0,05	355	352	343	343	340
	0,1	440	560	560	558	557

Palmitic acid - Co salt	0,15	535	565	615	615	615
Palmitic acid - Mn salt	0,05	129	168	229	231	228
	0,1	238	53	52	52	52
	0,15	267	269	270	270	270
Palmitic acid - Ni salt	0,05	1790	1710	1610	1605	1600
	0,1	1735	1605	1601	1535	1535
	0,15	1865	1857	1850	1850	1850
Palmitic acid - Zn salt	0,05	1735	1730	1720	1715	1715
	0,1	1790	1741	1732	1730	1730
	0,15	1825	1820	1810	1805	1805
Palmitic acid - Cu salt	0,05	1310	1305	1302	1302	1300
	0,1	1345	1335	1330	1325	1325
	0,15	1420	1415	1402	1402	1400
Diesel fuel	100	77	72	72	72	72

Initially, the electrical conductivity of diesel fuel without any additive was measured. The results of the study showed that the electrical conductivity of the diesel fuel was 77 pS/m after 1 day and decreased to 72 pS/m after 10, 20, 30, and 40 days.

However, when 0.05% of various metal salts (Co, Mn, Ni, Zn, and Cu) of natural petroleum acid were added to diesel fuel as antistatic additives, a significant increase in electrical conductivity was observed. After 1 day, the electrical conductivity values were 355, 129, 1790, 1735, and 1310 pS/m, respectively. After 10 days, the corresponding values were 352, 168, 1710, 1730, and 1305 pS/m, while after 40 days, they were 340, 228, 1600, 1715, and 1300 pS/m.

When the concentration of these additives was increased to 0.15%, the electrical conductivity of the diesel fuel increased further. After 40 days, the conductivity values reached 615, 270, 1850, 1805, and 1400 pS/m, respectively (Table 1).

As shown in Figure 2, the addition of 0.15% metal salts to diesel fuel resulted in a substantial increase in electrical conductivity compared with the untreated sample. The highest conductivity values were observed for the nickel and zinc salts, which maintained relatively stable performance throughout the 40-day period. In contrast, untreated diesel fuel showed very low conductivity during the entire storage period. These results indicate that the synthesized metal salts, particularly the nickel- and zinc-based additives, can significantly improve the antistatic properties of diesel fuel.

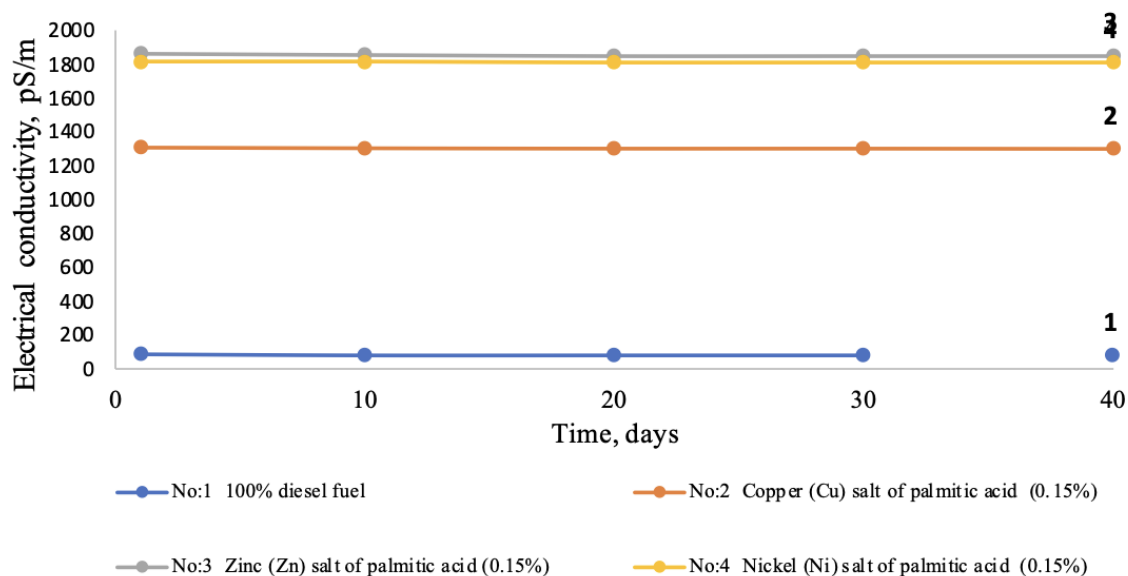


Figure 2. Graph illustrating the results of electrical conductivity of diesel fuel upon the addition of 0.15% cobalt (Co) and nickel (Ni) salts synthesized based on technical natural petroleum acid and its fraction.

CONCLUSION

The comprehensive experimental investigation carried out in this study clearly demonstrates that transition metal salts synthesized on the basis of natural petroleum acids represent highly effective antistatic additives for diesel distillate. The obtained results confirm that the incorporation of these metal–organic compounds into diesel fuel significantly enhances its electrical conductivity, thereby improving the dissipation of accumulated electrostatic charges and reducing the risk of ignition and explosion during storage, pumping, and transportation operations.

The electrical conductivity of untreated diesel fuel remained within the range of 72–77 pS/m, which is insufficient for efficient static charge relaxation under dynamic handling conditions. Upon the addition of synthesized metal salts at concentrations of 0.05%, 0.1%, and 0.15%, a substantial and systematic increase in conductivity was observed. This clearly indicates that metal carboxylates actively contribute to charge transport processes within the hydrocarbon medium by promoting ionic mobility and facilitating electrostatic discharge.

A comparative assessment of the investigated salts revealed a strong dependence of antistatic performance on the nature of the transition metal ion. Among the studied compounds, the nickel (Ni) salt exhibited the highest efficiency, increasing the electrical conductivity of diesel distillate to 1850 pS/m at a concentration of 0.15%. Zinc (Zn) salt demonstrated similarly high effectiveness, while copper (Cu) salt also provided significant conductivity enhancement. In contrast, cobalt (Co) and manganese (Mn) salts showed moderate but still appreciable improvements compared to untreated fuel. These differences can be attributed to variations in metal ion characteristics, including ionic radius, coordination ability, and interaction strength with the carboxylate group, all of which influence dissociation behavior and charge mobility in the fuel matrix.

Long-term monitoring over a 40-day storage period confirmed the stability of the antistatic effect, particularly for nickel and zinc salts. The conductivity values remained relatively consistent throughout the observation period, demonstrating good compatibility between the synthesized additives and the diesel fuel. Such stability is essential for practical industrial applications, where additives must maintain effectiveness during prolonged storage and transportation.

From a mechanistic perspective, the enhanced electrical conductivity can be explained by the amphiphilic structure of metal carboxylates, which contain both polar (metal–carboxylate) and nonpolar hydrocarbon fragments. This structural duality enables uniform dispersion in diesel fuel while simultaneously establishing conductive pathways that facilitate charge relaxation. The presence of metal ions increases the probability of partial ionization and promotes electrokinetic processes, ultimately reducing electrostatic charge accumulation.

The synthesis route employed in this work offers additional technological and economic advantages. The metal salts were obtained through straightforward neutralization reactions under relatively mild temperature conditions, followed by phase separation and solvent removal. The process does not require complex equipment or harsh reaction conditions, which enhances its scalability and industrial feasibility. Furthermore, the use of natural petroleum acids as raw materials contributes to resource optimization and supports the efficient utilization of locally available feedstocks.

In summary, the results obtained in this study demonstrate that transition metal salts of natural petroleum acids—particularly nickel and zinc salts—are highly promising antistatic additives for diesel distillate. Their ability to significantly increase electrical conductivity, maintain stability during storage, and be produced via a simple and economically feasible synthesis route highlights their strong potential for industrial application. The developed metal–organic systems represent an effective and practical solution for improving operational safety in diesel fuel storage and transportation systems.

REFERENCES

- [1] Putko, A. E. and Kitsis, S. I. Physical Foundations of the Electrification Phenomenon of Oil in Oilfield Pipelines, *Proceedings of the International Scientific and Technical Conference*, **2003**, v. 2, pp. 91–92, <https://bsj.esif.net/index.php/pahtei>
- [2] Abdullayeva, N. R.; Ismailov, T. A.; Mammadova, T. A.; Magerramov, R. S.; Veliyev, H. R. and Abbasov, V. M. Synthesis and study of antistatic diesel additives based on petroleum acids, *Petroleum Chemistry*, **2011**, v. 51 (4), pp. 299–302, <https://doi.org/10.1134/S0965544111030029>
- [3] Vlasova, E. P. and Kitsis, S. I. Investigation of the Influence of Oil and Pipeline Parameters on Oil Electrification Processes, *News of Higher Educational Institutions. Oil and Gas*, **2007**, (4), pp. 87–93, <https://bsj.esif.net/index.php/pahtei>
- [4] Li, X.; Deng, S. and Fu, H. Synergistic inhibition effect of two quinoline derivatives on the corrosion of carbon steel in HCl solution, *Corrosion Science*, **2012**, v. 62, pp. 163–175, <https://doi.org/10.1016/j.corsci.2012.05.008>
- [5] Verma, C.; Quraishi, M. A. and Ebenso, E. E. Heterocyclic compounds as green corrosion inhibitors: An overview, *Journal of Molecular Liquids*, **2019**, v. 276, pp. 30–42, <https://doi.org/10.1016/j.molliq.2018.11.081>
- [6] Finšgar, M. and Jackson, J. Application of corrosion inhibitors for steels in acidic media for the oil and gas industry: A review, *Corrosion Science*, **2014**, v. 86, pp. 17–41, <https://doi.org/10.1016/j.corsci.2014.04.044>
- [7] Umoren, S. A. and Gasem, Z. M. Oilfield corrosion inhibitors: Fundamentals and recent advances, *Journal of Industrial and Engineering Chemistry*, **2021**, v. 94, pp. 1–13, <https://doi.org/10.1016/j.jiec.2020.10.001>
- [8] Abbasov, V. M.; Rzayeva, N. Sh. and Ahmadova, S. Z. Study of Opportunities for Formation of Preservative Liquid Based on Sunflower Oil, *Processes of Petrochemistry and Oil Refining*, **2016**, v. 17 (3), pp. 262–265, <https://scholar.google.com/scholar?q=Abbasov+sunflower+oil+conservation+liquids>
- [9] Kitsis, S. I. and Putko, A. E. On the Theory of Oil Electrification in Oil Storage Tanks, *News of Higher Educational Institutions. Oil and Gas*, **2004**, (1), pp. 74–82, <https://elibrary.ru>

- [10] Abdullayeva, N. R.; Abbasov, V. M. and Ismailov, T. A. Synthesis of oxyesters obtained by interaction of natural petroleum acids with propylene oxide and study of their antistatic properties, *Chemical Problems*, **2009**, v. 3, pp. 551–553, <https://scholar.google.com/scholar?q=Synthesis+of+oxoesters+natural+petroleum+acids>
- [11] Mammadov, M. A. and Aliyeva, F. X. Synthesis of Monoethylamide Esters of Hexenylsuccinic Acid as Corrosion Inhibitors, *Azerbaijan Chemical Journal*, **2013**, v. 2, pp. 45–50, <https://doi.org/10.32737/0005-2531>
- [12] Abbasov, V. M.; Aliyeva, F. X.; Mammadova, G. F.; Agamaliyeva, D. B.; Jabbarli, S. F. and Huseynov, L. N. Monoamides of Malonic Acid as Effective Bactericidal Inhibitors, *Practice of Corrosion Protection*, **2023**, v. 28 (2), pp. 22–27, <https://scholar.google.com/scholar?q=Monoamides+of+Malonic+Acid+bactericidal+inhibitors> [
- [13] Abbasov, V.; Afat, C.; Chingiz, A.; Gultakin, Q. and Rufana, A. Environmental Impact of Oilfield Chemicals and Use of Secondary Raw Materials, *Journal of Cleaner Production*, **2023**, v. 380, pp. 134–145, <https://doi.org/10.1016/j.jclepro.2022.134892>
- [14] Yolchuyeva, U. J.; Jafarova, R. A.; Ibrahimova, R. A.; Alizada, R. A. and Alimardanova, F. N. Chromato-Mass Spectroscopic Study of Hydrocarbon Components of the Aromatic Fraction, *Petroleum Science and Technology*, **2024**, v. 23 (3), pp. 312–320, <https://doi.org/10.1080/10916466.2023.221456>
- [15] Bentiss, F.; Traisnel, M. and Lagrenée, M. The substituted 1,3,4-oxadiazoles: A new class of corrosion inhibitors of mild steel in acidic media, *Corrosion Science*, **2000**, v. 42 (1), pp. 127–146, [https://doi.org/10.1016/S0010-938X\(99\)00049-9](https://doi.org/10.1016/S0010-938X(99)00049-9) [
- [16] Abbasova, U. B. Application of Inorganic and Organic Complexes of Amino Derivatives of Natural Petroleum Acids as CO₂ Corrosion Inhibitors, *Processes of Petrochemistry and Oil Refining*, **2021**, v. 22 (1), pp. 152–158, <https://scholar.google.com/scholar?q=Abbasova+CO2+corrosion+inhibitors>
- [17] Hasanov, E. K.; Kengerli, A. A. and Alizade, R. A. Study of Imidazolines Based on Oleic Acid as Corrosion Inhibitors in Different Environments, *Academic Research in Educational Sciences*, **2024**, v.1, pp. 41–42, <https://scholar.google.com/scholar?q=imidazolines+based+on+oleic+acid> [
- [18] Abbasov, V.; Karimov, V.; Hasanov, E. and Alizade, R. Synthesis of Cr, Pb, Cu and Co Salts of Natural Petroleum Acids for Increasing Electrical Conductivity, *Fuel Processing Technology*, **2017**, v. 165, pp. 48–55, <https://doi.org/10.1016/j.fuproc.2017.05.012>
- [19] Ismailov, T. A.; Farhadova, R. M.; Ismailov, I. T.; Salmanova, C. K.; Alizade, R. A.; Ismailova, K. R.; Musayeva, N. M. and Aslanova, S. I. Study of the Na⁺ and K⁺ Salts of Ethanolamides as Corrosion Inhibitors, *Processes of Petrochemistry and Oil Refining*, **2025**, v. 26 (3), pp. 917–932, <https://scholar.google.com/scholar?q=Na+K+salts+ethanolamides+corrosion>
- [20] Abbasov, V.; Hasanov, E.; Agakishiyev, R.; Nabiye, E.; Kangarli, A. and Alizada, R. Study of Preservative Liquid and Corrosion Inhibitor Based on Oleic Acid Amidoamines, *Journal of Petroleum Science and Engineering*, **2024**, v. 230, pp. 112–125, <https://doi.org/10.1016/j.petrol.2023.111890>