International Journal of Advanced Research in Science, Engineering and Technology

ISSN: 2350-0328

Vol. 12, Issue 7, July 2025

Synthesis and analysis of modified resins derived from pyrolysis products

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ABSTRACT: This study examines the modification processes of Ustyurt gas pyrolysis fractions and the potential for obtaining high-quality homogeneous resins via polycondensation reactions. The primary technical properties of the synthesized resins, including their physical-mechanical characteristics, thermal and water resistance, elasticity, and adhesion to surfaces, were analyzed in accordance with ISO and GOST standards. Furthermore, the corrosion resistance of the modified resins was investigated. Potential application areas for the modified resins are also proposed.

I. INTRODUCTION

In industry, the quality of coatings used to protect metals and other construction materials particularly their resistance to corrosion and heat is of paramount importance. In recent years, interest in resin formulations derived from natural sources, including pyrolysis products, has grown significantly [1-2]. Pyrolysis fractions consist of liquid and solid hydrocarbons, alcohols, phenols, organic acids, and other compounds suitable for polycondensation reactions [3]. Studies have shown that incorporating graphene, metal oxides, and ferrocene-based modifiers can significantly improve the thermal stability and corrosion resistance of such resins in humid environments [4-5].

Research conducted in Europe and the United States has scientifically demonstrated the high temperature resistance, strong adhesion, and water-resistant properties of modified resins synthesized from pyrolysis products [6-7]. In particular, graphene-based water-soluble resins have shown excellent protective performance on galvanized steel surfaces, even in highly aggressive environments [3].

Experiments carried out in Russia and China have confirmed that phenol-formaldehyde resins modified with wood pyrolysis products exhibit enhanced physical-mechanical and chemical properties. This is especially important for the development of corrosion-resistant coatings designed for use in humid and acidic environments [1, 2, 8]. Furthermore, technologies for electrochemical purification and modification of pyrolysis oils derived from renewable fuels and polymer wastes have become a prominent research focus in recent years [4, 9].

Based on the above scientific sources, it can be concluded that modified resins derived from pyrolysis products—particularly those supplemented with graphene or metal oxide modifiers—have significant practical potential as coatings in high-temperature and chemically active environments [3, 5, 10].

II. GEO SCATTERED TYPE BIG DATA IN APPLICATION

In this study, for the first time, the composition of pyrolysis fractions from the Ustyurt region was investigated, and the physical-mechanical and corrosion-resistant properties of resins synthesized through their modification were analyzed. Compared to other regional pyrolysis fractions, these compositions exhibited high homogeneity, thermal stability, and resistance in moist environments.

International Journal of Advanced Research in Science, Engineering and Technology

ISSN: 2350-0328

Vol. 12, Issue 7, July 2025

Thermal and chemical modification processes carried out on aromatic hydrocarbons led to the synthesis of high-quality, homogeneous resins. These resins were found to be highly sensitive to temperature variations, with the efficiency of reactions differing across temperature ranges.

Various modification reactions were conducted using phenol, formaldehyde, and maleic anhydride derived from Ustyurt pyrolysis fractions. These processes included polycondensation, esterification, and the formation of network-structured resins via polyfunctional compounds. The corresponding chemical reaction equations elucidate the primary mechanisms underlying these transformations and represent the key factors determining the properties of the resulting resins.

Phenol-formaldehyde modification: $n\ ArOH + n\ CH_2O \rightarrow [-Ar\text{-}CH_2\text{-}]_n + n\ H_2O$
Maleic anhydride modification: $Ar\text{-}CH_2\text{-}OH + (CHCO)_2O \rightarrow Ar\text{-}CH_2\text{-}O\text{-}CO\text{-}CH{=}CH\text{-}COOH$
Polyfunctional modification: Resin + CH_2O + $(CHCO)_2O$ + Epoxy → Modified cross-linked resin

In this study, a preliminary analysis was conducted based on literature sources to evaluate the compositional characteristics of pyrolysis fractions and their potential for the synthesis of high-performance resins through modification with phenol, formaldehyde, and maleic anhydride. Subsequently, the chemical composition of the secondary pyrolysis product fractions from the Ustyurt Gas-Chemical Complex (GCC) and the modified resins derived from them was investigated. As a result, thermally stable, elastic, and corrosion-resistant resins were synthesized.

The table below (Table 1) presents the experimental outcomes, detailing the appropriate modification type for each fraction and the corresponding properties of the resulting resins:

Table 1. Types of modified resins based on Ustyurt GCC fractions and their key properties

№	Fraction type	Ingredients	Amount (%)	Suitable modification type	Type of resin produced
1	Pyrolysis distillate Pyrolysis condensate	Phenol	12.3	Phenol-formaldehyde polycondensation Maleine-based esterification	Thermal stable resin (solid) Elastic and hydrophobic resin
		Formaldehyde	8.5		
		Maleic anhydride	4.1		
2	Fraction type	Phenol	10.7	Suitable modification type	Type of resin produced
		Formaldehyde	7.9		
		Maleic anhydride	3.8		
3	Pyrolysis distillate	Phenol	11.5	Phenol-formaldehyde polycondensation	Thermal stable resin (solid)
		Formaldehyde	8.2		
		Maleic anhydride	4.0		

Each pyrolysis fraction in the composition of Ustyurt pyrolysis products yields a specific type of resin upon modification. A highly thermally stable solid resin was obtained via phenol-formaldehyde polycondensation using pyrolysis distillates. An elastic and hydrophobic resin was synthesized via esterification of the pyrolysis condensate with maleic anhydride. In turn, cross-linked corrosion-resistant hybrid resins were formed from heavy tar fractions through polyfunctional modification.

Moreover, by applying different modification methods to various pyrolysis fractions, it is possible to synthesize resins with distinctive thermal, mechanical, and chemical properties.

The following table (Table 2) presents the corresponding modification methods for each pyrolysis fraction, along with the resulting resin types and their analyzed physical-mechanical characteristics.

Table 2. Physical-mechanical characteristics of modified resins

№	Resin type	Hardness MPa	Elasticity %	Growth (in moisture) %	Corrosion resistance (hours)
1	Thermal stable resin (solid)	85	2.5	1.2	120
2	Elastic and hydrophobic resin	45	20	0.5	90
3	Mixed, corrosion resistant resin	70	8	1.0	150

Based on the data presented in the table, the resin obtained via polycondensation is characterized by high thermal stability and hardness, while the resin synthesized through esterification stands out for its elasticity and hydrophobic properties. The cross-linked, polyfunctionally modified resin demonstrates superior tensile strength and resistance to corrosion. The physical-mechanical properties of the modified resins derived from Ustyurt pyrolysis fractions indicate their high performance potential.

Furthermore, the physicochemical characteristics of the modified resins largely determine their practical applications. The resins synthesized from Ustyurt pyrolysis fractions exhibit varied curing temperatures, water resistance, and viscosity levels. These parameters make them suitable for use in various industrial fields, particularly in environments involving high temperatures and moisture. The table below (Table 3) outlines the key physicochemical parameters of the modified resins.

Table 3. Physicochemical properties of modified resins

№	Resin type	Curing temperature (°C)	Water resistance (24 hours, %)	Viscosity (mPa•s 25°C)
1	Phenol-formaldehyde resin	160	0.5	320
2	Maleic resin	170	0.3	280
3	Mixed resin	180	0.4	350

The hybrid resin demonstrates high thermal resistance and is convenient for use as a coating material, with a curing temperature of 180 °C and a viscosity of 350 mPa·s. The maleic anhydride-based resin exhibits the highest water resistance, with only 0.3% absorption, indicating excellent stability under humid conditions. The phenol-formaldehyde resin, in contrast, cures at moderate temperatures and provides reliable technical stability.

Furthermore, this study analyzed the corrosion resistance of the resins derived from secondary pyrolysis products of the Ustyurt Gas-Chemical Complex, using the standardized method GOST 9.401–91. The results are summarized in the table below.

Table 4. Corrosion resistance test results (GOST 9.401–91)

№	Resin type	Test environment	Duration (hours)	Corrosion Signs (ASTM D610)	Protection level (points/5)
1	Phenol-formaldehyde resin	In 5% NaCl solution	240	9 (Very Light)	4.5
2	Maleic resin	Waterproofing environment	168	Coating No Bubble	4.8
3	Mixed resin	Acidic environment (pH = 3)	168	9.5 (No Corrosion)	5.0
4	Mixed resin	High temperature (200°C)	100	Coating Unchanged	5.0

The hybrid resin demonstrated the highest corrosion resistance across all test environments. The maleic anhydride-based resin exhibited excellent stability during hydro-insulation testing. Although the phenol-formaldehyde resin showed moderate protective performance, it meets the operational requirements of industrial applications. Overall, the hybrid resin proved to possess the most versatile protective properties.

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 12, Issue 7, July 2025

ISSN: 2350-0328

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Based on the test results, the modified resins, due to their high thermal resistance, resistance to water, acidic and saline environments, elasticity, and adhesion characteristics, have demonstrated high efficiency as coating and insulation materials in industrial applications.

During the synthesis of resins obtained through the modification of pyrolysis fractions from the Ustyurt Gas-Chemical Complex, temperature and reaction time significantly influenced the reaction efficiency and product homogeneity. Identifying optimal technological parameters was essential for obtaining high-quality, thermally stable resin. The key measurements and results from this process are presented below.

The following table (Table 5) shows the resin yields obtained at various temperatures and their corresponding productivities.

Table 5. Resin yield and productivity at different temperatures

№	Temperature °C	Reaction time (hours)	Yield (%)	Pitch quality (in terms of homogeneity)
1	150	1	65	Average
2	150	2	70	Good
3	200	1	75	Good
4	200	4	82	Very good

Increasing temperature and prolonging the reaction time lead to higher resin yield; however, the optimal parameters were identified within the range of 180–200 °C and 2–4 hours.

Applications of the resins: The results of this study demonstrate that modified resins obtained from pyrolysis fractions of the Ustyurt Gas-Chemical Complex can be effectively applied across various industrial sectors. In particular, the hybrid phenol-maleic anhydride-based resin exhibits high corrosion resistance in acidic and aggressive environments, making it an excellent protective coating for metal surfaces. The maleic anhydride-based resin, due to its high elasticity and water resistance, is a suitable choice for electrical insulation materials. Meanwhile, the phenol-formaldehyde resin, with its superior thermal stability, serves as an effective material for heat-resistant coatings and structural elements.

Laboratory tests conducted in accordance with GOST 9.401–91 and ISO 9227 standards confirmed that all resin types exhibit resistance to corrosion, moisture, and high temperatures.

III. CONCLUSION

High-quality, thermally stable, elastic, and corrosion-resistant resins were synthesized based on phenol, formaldehyde, and maleic anhydride through various modification methods applied to pyrolysis fractions from the Ustyurt Gas-Chemical Complex. Each modification technique imparted specific physical-chemical and mechanical properties to the resins, demonstrating their effective use as corrosion-resistant coatings, insulation, and structural materials across diverse industrial applications. Correct selection of technological parameters proved critical to enhancing product quality.

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