Chapter 2

Sources of Active Ingredients for Sustainable Corrosion Inhibitors

Rekha Sharma¹, Sapna Nehra², and Dinesh Kumar^{3*}

¹Department of Chemistry, Banasthali University, Rajasthan-304022, India

²Department of Chemistry, Dr. K. N. Modi University, Newai, Rajasthan 304021, India

³School of Chemical Sciences, Central University of Gujarat, Gandhinagar-382030, India

* dinesh.kumar@cug.ac.in

Abstract

Metal corrosion is a grave problem, having deleterious effects on human health, the economy, the environment, and many engineering schemes, for example, automobiles, aircraft, naval vessels, and pipelines. For the confirmation of enduring reliability and stability of alloys and metals, corrosion-protective surfaces are of the greatest significance, for example, ions and water, through restraining their interactions with corrosive species. Though, their applied submissions are frequently bounded whichever through deprived mechanical robustness or else through the incapability to resist low surface tension liquids, for example, alcohols and oil. In this chapter, we have focused on diverse materials as sustainable corrosion inhibitors such as organic corrosion inhibitors, green corrosion inhibitors, and polymer-based corrosion inhibitors to protect materials from being corroded. Amongst them, we especially focus on green corrosion inhibitors as a consequence of simple manufacturing, easy availability, cost-effectiveness, and biodegradable nature.

Keywords

Cost-Effective, Sustainable, Renewable, Corrosion, Applications

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1. Introduction

Corrosion is an enhanced method of aging that producing hefty commercial forfeitures at the international/national scale and takes place through electrochemical or else chemical reactions of resources with their environments [1]. Corrosion is a thermosensitive method that can be condensed to a certain degree through using many methods such as designing, surface cleaning, use of inhibitors, alloying, coatings, and paints, but it cannot be eliminated [2–5]. Because of their simple submission and periodic shielding of industrial infrastructures, synthetic polymer coatings have been widely utilized amongst these methods to avert corrosion, by which it can reduce the cost of corrosion and its conservation [6]. Though, for the growth of maintainable polymers, via adaptable monomers, the impression of emission of VOCs and fossil fuel depletion through their dispensation have fascinated the researcher’s attention [7]. Out of them, low molecular weight containing vegetable oil-based polymers of having decent variability with insignificant or no carbon-based diluents and invent common submissions in flavors, pastes, coatings, and dyes [8,9].

2. Corrosion inhibitors

In various corrosive media, to discover corrosion inhibitors of organic origin, substantial exertions have been organized over the years [10-13]. For protecting various materials from corrosion various compounds such as sulfur-containing compounds, N₂ based materials in an acidic medium and their byproducts, acetylenic, thioaldehydes complexes, aldehydes, and numerous alkaloids, for instance, strychnine, quinine, nicotine, and papaverine are utilized as corrosion inhibitors, whereas, nitrite, benzoate, phosphate, and chromate perform as decent inhibitors in neutral media. Inhibitors avert or diminution of the metal reacts with the reaction medium. These inhibitors decrease the degree of corrosion through the following methods:

- intended for substrates to the surface of metal, plummeting the degree of diffusion
- onto the surface of the metal, sorption of molecules/ions
- decreasing or increasing the cathodic or anodic reaction,
- inhibitors that have in situ submission benefit and are frequently easy to use

Many features such as easy obtainability, amount and cost, and vitally wellbeing to the atmosphere and its species are required for consideration when selecting an inhibitor.

2.1 Organic inhibitors

Organic inhibitors have a higher electron density and basicity and therefore perform as a corrosion inhibitor, which usually partakes heteroatoms such as N, S, and O. On the metal surface, these heteroatoms (N, O, and S) are the lively cores' adsorption. The sequence $O < N < S < P$ ought to follow for inhibition competence. To decrease the occurrence of steel deterioration, the usage of organic composites comprising O, S, and specifically N has been studied earlier. The outcomes displayed that on the metal surface, utmost organic inhibitors adsorbed through forming a compact barrier with water molecules and moving it on the surface. The electron transfers to the metal from the inhibitor facilitated through the accessibility of p-electrons and lone pair (nonbonded) in inhibitor molecules. A coordinate covalent bond can be shaped concerning the allocation of electrons to the surface of the metal ion from the inhibitor. To recover the inhibition process various functional groups i.e., Nitro, Aldehyde, Carboxylic acid, or Amine is substituting the C in the ring bonded to an H atom [13]. The electron density of metal varies at the site of add-on ensuing in the deceleration of the anodic or cathodic responses. Straight chain amines have been observed containing carbons between 3-14. In the capability to prevent corrosion arises, inhibition small decrease or increase with higher members, nonetheless sharply increases with 10 carbons number in the carbon chain. Though, the solubility of the inhibitors may be increased due to the attendance of hydrophilic functional moieties. The physicochemical possessions and chemical structure of the composite are the outcomes of organic inhibitor, for example p-orbital character, functional moieties, molecular electronic assembly, and the electronic mass at the contributor particle. The inhibition might be possible because of the following points:

- Increase in an overvoltage of cathodic and anodic site
- Adsorption of molecules or ions of cathodic or anodic places
- The establishment of a protecting fence film.

The aspects that contribute to inhibitory action are:

- Molecular size
- Bond strength and chain length
- Atomic bonding
- Atmospheric solubility
- Cross-linking ability.

In contradiction of acid attack, to create a fence of solitary or numerous molecular layers, the inhibitors play an important role. Concerning the charge transfer beginning from one to another end, they frequently relate this protecting act to physical or chemical adsorption. Having several substituents, S and N, comprising heterocyclic complexes, are measured to be an operative deterioration inhibitor. In acid solutions, to inhibit corrosion of metals, some materials propose a special affinity, for example, hydrazine derivatives and thiophene. Inorganic materials, for example, chromates, phosphates, silicates, dichromates, tungstates, borates, arsenates, and molybdates, have been originating operative as metal deterioration inhibitors. In acid conditions, spinoffs of pyrrole are supposed to display a decent shield contrary to deterioration. In preparing anticorrosive and primers coatings, these inhibitors have also attained helpful submission. For the adsorption process, the inhibitive features of such composites acting as the reaction center. To protect metal disbanding from acid solutions, inhibitors are frequently added in manufacturing procedures. To progress nontoxic, inexpensive, and ecological procedures have fascinated the researcher's attention to the emphasis on the usage of natural products, the recognized dangerous belongings of utmost artificial organic inhibitors. Progressively, considering Cr(VI) existence debarred and categorized as a hazard, it is required to establish cultured novel coverings for the enhanced recital. The utmost choice of shielding metals contrary to corrosion is the usage of inhibitors. Many inhibitors in usage are selected thru composites partaking heteroatoms in their long-chain or aromatic carbon system, and synthesized by inexpensive raw material, out of them, most of these inhibitors are poisonous to the atmosphere. This fascinated the researcher's attention to develop corrosion inhibitors using green method [14].

3. Green inhibitors

These inhibitors do not comprise toxic compounds such as heavy metals and other elements, and these are biodegradable. In alkaline or acidic atmosphere, to hinder the metal corrosion, an efficacious usage of naturally ensuing constituents has been reported by some research groups.

As a deterioration inhibitor for Cu, El-Etre reported natural honey [15], and also reported opuntia extract on aluminum as an inhibitor [16], at 25 °C for the Al+2.5Mg alloy, rosemary leaves described as deterioration inhibitor in a 3% NaCl solution [17], and the deterioration of aluminum in HCl inhibited by *Delonix regia* extracts [18]. In HCl solution, the deterioration of SX 316 steel was regulated via potentiostatic technique in addition to weight loss capacities using the seed extract of *Ammi visnaga* (khillah). Because of interaction among iron cations, the method of action is accredited to form insoluble compounds [19]. The ethanolic extract of *Carica papaya* leaves were utilized for the corrosion inhibition of mild steel in H₂SO₄ by Ebenso et al. [20]; Corrosion inhibition of mild steel by African bush pepper (*Piper guinensis*) [21]; Corrosion inhibition in H₂SO₄ of mild steel using *Azadirachta indica* leaves extract (neem) [22]. Zucchi and Omar [23] reported extracts of different plant i.e., *Poinciana pulcherrima*, *Papaia*, *Datura stramonium* seeds, and *Cassia occidentalis*, and *Auforpio turkiale*, *Azadirachta indica*, *Calotropis Procera B*, and *Papaya* for their potential towards corrosion inhibition. The outcomes displayed that the steel corrosion reduced by all the plant extracts excluding *Azadirachta indica* and *Auforpio turkiale* with efficiency in 1N HCl of 88%–96% and which decreases slightly in 2N HCl. Umoren et al. [24], reported the mild steel corrosion inhibition in H₂SO₄ in the attendance of synthetic polymer i.e., polyethylene glycol (PEG) and naturally occurring polymer i.e., gum arabic (GA), they attributed the outcome of these plants to the harvests of protein content hydrolysis [23]. The results showed that GA was found to be less effective than that of PEG.

Particularly in environmental technologies and sustainable energy, Gong et al., 2016 reported graphene with pristine graphene and its analogs of GO and RGO. There are many effective belongings of graphene submissions, from detecting energy storage and conversions to ecological treatment. Graphene is virtually enduring united by alternative vigorous substantial as a compound in preference to the occurrence as a separate operating substantial. The interaction through graphene benefits to reduce such limits in the unadorned used material and emphasizes them with its effective transfer of heat, elevated surface to bulk ratio, and conduction of an electron. The approach of exterior functionalization of graphene to accomplish this grasps the significant to permitting the production of high-performance complexes, with either oxide semiconductors, metal NPs (solid inorganic matters), or molecular linkers, organics, proteins (soft matters) [25].

Gerengi et al., 2011 reported the corrosion inhibition by extract of *Schinopsis lorentzii* was intended for utilizing Tafel extrapolation, linear polarization, and EIS of low carbon steel with diverse concentrations of 1M HCl solution. The results showed that with the upsurge concentration of extract of *Schinopsis lorentzii*, efficacies of inhibition augmented, which

performed as somewhat cathodic inhibitor. It was demonstrated that in the HCl atmosphere, the low carbon steel corrosion inhibition resulted by *Schinopsis lorentzii* extract.

In view of the inhibition efficacy, the electrochemical procedures i.e., LPR, TP, and EIS utilized in this study display comparable outcomes on *Schinopsis lorentzii* extract. The extract of *Schinopsis lorentzii* might be utilized as a substitute in acid pickling and acidization of mild steel for toxic chemical inhibitors, and it is also an ecologically and naturally occurring material [26].

Based on three corrosion inhibitors: mercapto-benzimidazole, mercapto-benzothiazole, and benzotriazole loaded with halloysite nanotubes, Joshi et al., 2013 developed long-lasting anticorrosive coatings for steel. The oil-based alkyd paint at 5–10 wt%, together with corrosion healing and continued agent release in the coating defects, were admixed with the inhibitors' loaded tubes. In the anticorrosion efficacy of the coatings, the sluggish inhibitor proclamation (20–30 h) at flaw facts produced an outstanding upgrade. At nanotube ends the development of release stoppers with copper-inhibitor complexation and urea-formaldehyde copolymer, the time growth has been attained of anticorrosion agent release. Through the micro scanning of growth of corrosion current through reviewing paint adhesion and microscopy examination, in a 0.5 M NaCl solution, the corrosion protection efficacy on ASTM A366 steel plates was tested. The finest shield was attained via benzotriazole and halloysite/Mercapto-benzimidazole inhibitors. Consequently, by the longer release of inhibitors, and added an upsurge in corrosion efficacy provided through the development of stoppers by a copolymer of urea–formaldehyde.

For the growth of additional useful coatings, for example, antimicrobial, antifouling, and flame retardant that helpful from the controlled release and encapsulation of the vigorous agents, this method might be useful [27].

Amongst numerous choices for industrial-scale CO₂ capture, RTIL systems are likewise existence verified as a probable replacement to report the disadvantages of aqueous alkanolamine grounded advanced method. To hinder the existence of corrosion, these novel arrangements appear as an improved substitute. In water-based chemical absorption methods, oversight of the aqueous phase marks the elimination of plausible oxidizing classes primarily accountable for corrosion. By the steadily searching the outcome of process temperature, amine/RTIL type, in flue gas absence/presence of O₂, loading of CO₂, besides the effect of amount of water, the corrosion procedure in RTIL mixtures comprised hydrophilic RTIL ([EMIM][Otf], [BMIM][BF₄], and [EMIM][BF₄]) and alkanolamines have been examined. The adsorption of toxic materials on corrosion inhibitors was done by various analytical tools such as EDX, SEM, and LPR.

An extremely operative and cost-effective scheme is vital, which may hamper the CO₂ flow hooked on the atmosphere to handle anthropogenic GGE. The outcomes were associated through aqueous alkanolamine systems to test their suitability and to study the corrosion rate in alkanolamine–RTIL solutions of carbon steel 1020.

The experimental data showed the following conclusions:

- [BMIM][BF₄] and [EMIM][BF₄] ionic liquids established a comparable trend in grouping with alkanolamines and displayed outstanding control of corrosion in the pure state. However, because of the attendance of acidic impurities, clean [EMIM][Otf] was moderately corrosive in the electrode's direction surface, mainly.
- An advanced gas loading additionally enhanced the corrosion inhibition competence of amine–RTIL blends in contradiction of aqueous amine systems.
- The damaging consequence of the liquid fillings shields the metal surface by the development of a protecting film, which was demonstrated by EDX analysis. Furthermore, on the protecting ability of amine–RTIL mixtures contrary to corrosion, the absence/presence of H₂O and O₂ did not enclosure harmful effects at all [28].

In corrosive media like ionic liquid, organic, and aqueous media, Chatterjee et al., 2014 demonstrated the nanostructured silicon electrochemical steadiness permitted thru heterogeneous boundaries of conformal few-layered graphene. The passivation ($d = 0.35$ nm) of few-layered graphene preserved through direct gas-phase, which is transportable to P-Si materials besides Si-NPs. For Si-NPs, the unpassivated Si-NPs impulsively liquify, whereas the graphene-passivated Si corresponds to endure physical deterioration. They are empowering these materials for electrochemical supercapacitors for P-Si, the electrochemical steadiness thru extensively diverse electrolytes together with NaOH. They emphasized the straight establishment of nanostructured silicon on few-layered graphene transversely energy storage, electronics, energy conversion, biological systems, and detection because the superficial interactions only command the use of nanoscale silicon in varied submissions resultant to formulate heterogeneous on-chip boundaries which could preserve steadiness in even the utmost sensitivity towards surroundings.

For usage in a variety of chemical and biological surroundings, this work highlighted on atomically thin graphene passivation layers to permit Si-NPs platform for silicon material that is chemically versatile, and its manufacturing is cost effective. Particularly, to assimilate energy stowage hooked on present technical substantial contexts, the view of on-chip increased power energy stowage permits a comprehensive podium, applicable for detection, solar conversion, and electronics, besides emergent podiums, for example, implantations and recyclable systems [29].

Baek et al., 2012 reported the synthesis of green corrosion inhibitors using three-step reactions, i.e. click coupling reaction, esterification reaction, and nucleophilic substitution reaction using n-dodecyl succinate spinoffs comprising two DSE or HSE. The formation of succinate derivatives has been characterized using many analytical tools such as FT-IR, ^1H NMR, and EDX analysis. The weight loss and ASTM D665 methods were utilized to investigate the corrosion averting possessions of the ending harvests. It was found that because of the occurrence of succinate derivatives in paraffin oil, the strength of corrosion protection possessions was not principally determined by the functional groups or their length, but it was determined via the attentiveness of alkyl chains.

In the synthesis mechanism, the succeeding reactions occur:

- The first reaction occurs from sodium azide to an alkyl halide is the nucleophilic substitution reaction.
- Second, amongst propargyl alcohol and alkyl azide is the click coupling reaction.
- Third, amongst triazole alcohol and dodecyl succinic anhydride is the esterification reaction.
- The results showed that the DSE showed slighter low corrosion inhibition efficiency at low concentrations than the HSE, which shows that on the steel surface, the -COOH groups can improve the development of the lubricant layer to some amount. Alternatively, the corrosion inhibition efficacy augmented on a growing quantity of DSE and HSE spinoffs. The DSE and HSE spinoffs displayed the same efficacies towards inhibition of corrosion at high concentrations. The outcomes show the efficiency of HSE and DSE towards green corrosion inhibitors [30].

Hasib-ur-Rahman et al., 2013 reported aqueous alkanolamine-based CO_2 capture procedures as a major concern for corrosion. In aqueous monoethanolamine solvents, for the control of the corrosion process, they examined the competence of an almost nonvolatile and thermodynamically steady RTILs. The [emim][DCA], [emim][Otf], [emim][tosylate], and [emim][acetate] were the four imidazolium-based RTILs having ethyl side chains which have been selected for the purpose of corrosion. In industrial installations, for the process of corrosion, carbon steel 1020 which has been utilized as a test material is extensively utilized as a construction material. Electrochemical corrosion tests for measuring corrosion current were carried out via the LPR method, therefore, permitting the ensuing rate calculation of corrosion by the Tafel fit technique. In alkanolamine-based advanced CO_2 capture schemes, the [emim][acetate] is the utmost accomplished beyond the verified ionic liquids of restoring the various working difficulty of corrosion.

Through the oxidants hindering drive in the direction of the metal surface, these RTILs look to check the corrosion method if possible, owing to their higher viscosity. Though, thru in view of the ionic liquids that have an improved attraction for carbon steel and added methodical analysis is essential [31].

Pathan et al., 2013 reported the surface covering manufacturing is worldwide intricate in emerging biodegradable, valuable, and VOCs free covering schemes, which exhibit auspicious corrosion inhibition and physicochemical recital. In this, the author reported the fabrication of BMF modified SA-BMF. The molecular weight and mechanical illumination of SA and SA-BMF resin were examined thru GPC methods and ^1H NMR, ^{13}C NMR, and FT-IR spectroscopy. The physico-mechanical and physico-chemical possessions were verified by standard procedures. The TGA analysis was utilized to quantity initial temperature decay. The glass transition temperature and curing study were measured using the thru DSC. The contact angle was used to determine the hydrophobicity of the coatings. The EIS and polarization methods were utilized to examine anticorrosion recital of SA-BMF. Inclusively, the waterborne SABMF covering showed bend tests (flexibility retentive 1/8 in.), scratch resistance, and developed impact resistance (150 lb/in.), together with decent anticorrosive recital and antibacterial action.

For the surface covering manufacturing, the PDP contact angle and EIS studies exposed virtuous rust prevention recital in contrast to alkaline, acid, and tap water media make them appropriate [32].

For antimicrobial and anticorrosion action, Oguzie et al., 2013 reported capsicum frutescens (CF) extracts. In acidic media, the antimicrobial efficiency of ethanol, methanol, petroleum spirit, and water extract correspondingly contrary to the corrosion-associated SRB, *Desulfotomaculum* classes, was measured utilizing the agar disc diffusion method, whereas the anticorrosion significance on low carbon steel of the ethanol extract was deliberated practically utilizing impedance, polarization, and gravimetric methods. Because of the accomplishment of the phytochemical ingredients existing within the structure, together with 39.2% saponins, 0.4% tannins, and 8.8% alkaloids, CF extract efficiently prevented SRB growth and corrosion equally. The antimicrobial outcome consequences from vital metabolic purposes and disturbance of the growth of the SRB, whereas the corrosion course was prevented thru adsorption on the steel surface of organic extract material. To the corrosion preventing the act of the extract, dihydro-capsaicin, and capsaicin, and afforded molecular level visions on their separate contributions, MD imitations were completed to demonstrate theoretically, the adsorption performance and electronic assembly of the lively alkaloidal ingredients extract of CF [33].

For the generation of VOCs free coatings and paints, Rahman et al., 2017 reported HBA–BMF– Fe₃O₄ spherical designed oleo alkyds which uphold decent fluidity, low viscosity and perform a vital part for the efficacy towards corrosion prevention. The pentaerythritol, SO, and phthalic anhydride were used to synthesize HBA (Hyperbranched alkyd). For the synthesis of the HBA–BMF– Fe₃O₄ nanocomposite for anticorrosive coatings, a sonication method was used to disperse the Fe₃O₄ NPs (magnetite) in HBA–BMF. To assess morphological, structural, thermal, physico-mechanical, anticorrosive, and electrochemical possessions of these coatings, the ASTM techniques were utilized. The coverings of HBA–BMF and HBA–BMF–Fe₃O₄ nanocomposite displayed virtuous physicomachanical possessions and suppleness. The outcomes of electrochemical corrosion studies demonstrate that in comparison to HBA–BMF, the HBA–BMF–Fe₃O₄ nanocomposite coverings display greater corrosion prevention recital having 1.0×10^{-4} mpy of at 107 Ω of impedance value [34].

Upadhyayula et al., 2017 reported graphene-modified PEI coatings as a key apprehension for bare steel in susceptibility to neighboring corrosion and structural submissions. HDG coatings suffer from the need for recurrent maintenance cycles, and difficulties associated with shorter service exist. To address these problems, Graphene-modified PEI coverings have been predictable as appropriate substitutes for corrosion inhibitors. Though, to comprehend the potential ecological effects of these coatings, general anxieties concerning the insinuations of nanomaterials make it necessary. To progress covering adsorption, the detection studies reveal that the probable influences insensitive to the usage of chemically or thermally functionalized graphene are tremendously sensitive to the conservation requirements and amenity lifespan of the covering [35].

A first-generation biofuel that presently exists as a biocomponent blended with types of gasoline reported by Matějovský et al., 2019. Combinations of gasoline and ethanol are elected as EGBs. To numerous nonmetallic and metallic resources due to moisture affinity and elevated polarity of ethanol, which significantly affect the possessions of the subsequent EGB, including their viciousness. Through corrosion inhibitors, the EGBs corrosion aggressiveness might be diminished. The E10, E25, E60, and E85 fuels are the three corrosion inhibitors for the inhibition of corrosion which have been reported on mild steel. The verified inhibitors were DET, A and two compound inhibitors comprising DBS, PA, and ODA. For the DETA concentration of 100 mg·L⁻¹, the inhibitory efficacy was found to be 98% in the E60 fuel [36].

For the high-density petroleum resulting fuels, Liang et al., 2015 reported renewable substitutes as energy-dense terpene biofuels. Coastal sediment/seawater developments incubated underneath simple anaerobic circumstances and were revised with TDF or a mixture of consequential petroleum hydrocarbons [37].

AlHarooni et al., 2016 emphasizes on evaluating 6 investigative methods to examine the deprivation state of many MEG solutions comprising FFCI and MDEA that were thermally treated to 135 °C - 200 °C for the corrosion and gas hydrate establishment inside gas pipelines which are two key problems towards flow assurance. The investigative methods appraised are electrical conductivity, pH measurement, ion chromatography (IC), alteration in physical features, HPLC-MS, and GHIP (using CH₄ gas at 50 to 300 bar pressure with MEG solutions having 20 wt %). This study mainly focusses on the effect of degraded MEG on corrosion inhibition and gas hydrate because of the deficiency of the value controller [38].

Matějovský et al., 2018 described the bioethanol might be partake a significant stimulus proceeding towards complete thermo-oxidative steadiness and further hooked on types of n gasoline, expressively varies the chemical and physical possessions of the ensuing fuels. The authors synthesized ethanol–gasoline blends (EGBs) E10, E25, E40, E60, and E85 contingent on their initiation period and were artificially oxidized [39].

Similarly, inside a failed nuclear waste container, to inhibit corrosion of consumed nuclear fuel, Liu et al., 2016 reported a combination of H₂ from H₂O₂ disintegration and many reactions concerning liquified H₂ formed whichever thru α radiolysis otherwise thru the deterioration of the steel container vessel [40].

Conclusion

In this chapter, various materials have been discussed which were utilized as corrosion inhibitors to prevent metal deterioration. The inhibitors showed high adsorption efficiencies towards toxic substituents adhere to on the metal surface and cause corrosion. These materials are highly cost effective, elevated potential, clean, renewable, sustainable source of energy, and cost-effective owing to the population growth and fast progress in response to the ecological concerns and ever-increasing global energy request. Therefore, they have a future perspective the energy conservation and deterioration prevention and fascinate the researcher's attention.

Abbreviations

VOCs = Volatile organic compounds

GO = Graphene oxide

RGO = Reduced graphene oxide

EIS = Electrochemical impedance spectroscopy

RTIL = Alkanolamine/room-temperature ionic liquid

LPR = Linear polarization resistance

SEM = Scanning electron microscopy

EDX = Energy-dispersive X-ray spectroscopy

GGE = Greenhouse gas emissions

P-Si = Electrochemically etched porous silicon

Si-NPs = Silicon nanoparticles

DSE = triazole groups

DSE = two triazole groups

HSE = one triazole groups

LPR = Linear polarization resistance

BMF modified SA-BMF = Butylated melami-e formaldehyde -modified soy alkyd

GPC = Gel permeation chromatography

TGA = Thermogravimetric analysis

DSC = Differential scanning calorimetry

EIS = Electrochemical impedance spectroscopy

SRB = Sulfa-e reducing bacteria

MD = Molecular dynamics

Mpy = Mils per year

PEI = Poly(ether imide)

EGBs = Ethanol–gasoline blends

DETA = Diethylene triamine

DBS = Dibenzyl sulfoxide

PA = Propargyl alcohol

ODA = Octadecyl amine

HPLC-MS = High performance liquid chromatography–mass spectroscopy

GHIP = Gas hydrate inhibition performance

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