Chapter 4

Polysaccharide as Green Corrosion Inhibitor

Y. Dewangan, A.K. Dewangan, D.K. Verma*

Department of Chemistry, Government Digvijay Autonomous Postgraduate College,
Rajnandgaon, Chhattisgarh, INDIA, 491441

*dakeshwarverma@gmail.com

Abstract

The carbohydrates associated with polysaccharide glycosidic bonds are tightly chained, usually linear and highly branched complex molecules. Their structure mainly consists of hydroxyl groups in the form of functional groups, in which an oxygen heterogeneous atom is present. Some polysaccharides have hetero atoms. Nitrogen and Sulfur in addition to oxygen, which have unshared electron pairs. Hetero atoms easily share their electron pair to the vacant *d* orbitals of the metal ion and prevent the metal from corrosion. Polysaccharides are biodegradable, renewable, inexpensive and environment friendly due to which they are easily used as corrosion inhibitors. The present study mentions some major research work in which polysaccharides are used as corrosion inhibitors. Their mixed type nature has been reported in most research papers, and in the case of steel metal, they mainly follow the Langmuir adsorption isotherm. Chemical (gravimetric analysis) and electrochemical (EIS & PDP) studies are frequently used for the corrosion inhibition study. Some of the current research papers have also used computational or theoretical studies such as quantum chemical study and MD simulation. At the end of this book chapter, a discussion is also given regarding further research and direction related to the topic.

Keywords

Polysaccharide, Heteroatom, Metal, Corrosion Inhibitor, Electron Impedance Spectroscopy, Density Function Theory

Contents

Polysaccharide as Green Corrosion Inhibitor	70
1. Introduction.....	71

2. Polysaccharides as prominent corrosion inhibitor.....	72
2.1 Corrosion inhibition of ferrous materials	72
2.2 Corrosion inhibition of non-ferrous materials.....	84
3. Adsorption mechanism.....	89
4. Further aspects.....	91
Conclusion.....	91
Acknowledgement	92
Abbreviations	92
References	92

1. Introduction

Due to the usefulness of metals and alloys, it is very important to research the cause of corrosion and their inhibition. Commonly HCl and H₂SO₄ Corrosive Media are used to study Corrosion Behavior in metals and alloys. During Acid pickling, Chemical cleaning and Rust cleaning, these acids are used frequently which causes loss of metals [1-3]. Corrosion inhibitors are used to prevent this loss of metals, even small amounts of which are useful in preventing metal corrosion, thereby prolonging the lifespan of metals. Most reported corrosion-resistant organic compounds are expensive, hazardous, and toxic in nature from manufacture to use, due to which continuous research is underway to reduce their use to a great extent [4]. In this direction, using natural corrosion inhibitors is an inexpensive and simple method, which is biodegradable, cheap and environment friendly. There is some old research in which various scientists and engineers used the products derived from the plant such as root, fruit, flower, stem, gum, and water as green corrosion inhibitors [5-11]. Polysaccharides are natural polymers that are environmentally friendly, biodegradable, inexpensive and stable due to which they are used as metal corrosion inhibitors. These are inexpensive as well as renewable and are readily available which contain OH groups, hetero atoms, and alkyl chain lengths, due to which they are easily deposited onto the metal surface. Some of the major works mentioned in this book chapter are used as corrosion inhibitors [11-15]. From the above research, it can be concluded that plant extract usually contains complex organic compounds like amino acids, proteins, alkaloids, tannins, and carbohydrates [16]. These biomolecules have polar functional groups, which are mainly hetero atoms such as O, N, P, S and polygons [17]. Their structure reflects physiochemical adhesion between the organic molecule and the

metal surface, which is a kind of donor acceptor property. Due to such a structure, they are easily absorbed on the metal surface, and form protective layers that block the active site of the metal surface for further corrosion. EIS and PDP are extensively used for the electrochemical analysis for inhibition determination [18,19]. Similarly, SEM-EDS applied for modification seen on the metal surface. DFT calculation and MD simulation are extensively used as theoretical calculation [20-23]. Fig. 1 represents the general characteristics of corrosion inhibitor.

Figure 1. General characteristics of corrosion inhibitor.

2. Polysaccharides as prominent corrosion inhibitor

2.1 Corrosion inhibition of ferrous materials

HPMC has been applied as potential corrosion inhibitor for MS corrosion in aggressive solution. HPMC follows Freundlich adsorption isotherm and its mixed type nature has been reported. According to EIS analysis HPMC exhibited 91.18 % I when applied with KI i.e. synergistic effect [24]. Guar gum applied as potential corrosion inhibitor for carbon steel in corrosive solution (M. Abdullah 2004) and reported that it follows Langmuir adsorption isotherm. Weight loss study shown the surface coverage (θ) of 0.939 in 1500 ppm concentration of inhibitor [25]. M. Mobin et al. (2011) applied various

techniques like WL, PDP, SEM, where weight loss reveals 67.41 % inhibition efficiency in 500 ppm concentration at 30°C of starch and surfactants. ΔG adsorption value -35.54 KJmol⁻¹ observed at 30°C when starch applied with CTAB [26]. Synergistic effect of Gum Acacia and surfactants namely CTAB and SDBA used as corrosion inhibitor for mild steel in corrosive solution (0.1 M H₂SO₄). Analysis performed at temperature ranging from 30°C to 60°C [27]. Synergistic effect of Xanthan gum with surfactants was applied as corrosion inhibitor. 74.24 % ion-exchange efficiency (*IE*) obtained with XG at 1000 ppm at 30°C. Techniques such as UV-VIS, SEM, EIS and DFT calculation are applied for inhibition analysis [28]. UV-VIS, AFM, SEM, FTIR and EIS techniques are applied to check the efficiency of Plantago (polysaccharide) for carbon steel corrosion in acidic medium (1M HCl). -250 to +250 mV applied for electrochemical analysis (PDP) and found 86.11% *IE* at 400 ppm concentration [29]. EIS, SEM, PDP, WL analysis reveals that mixed type nature of pectin for MS in corrosive solution. Corrosion rate of 0.062 mg cm⁻²h⁻² and inhibition efficiency of 90.3 are obtained at 2 g/L amount of inhibitor [30]. Analysis suggest the Dubinin-radushkevich and Langmuir adsorption isotherm of CMC at 30°C to 60°C and 64.8 inhibition efficiency as per weight loss analysis [31]. Reported methods suggest the potential property of HEC towards carbon steel and follows the Langmuir model [32]. Modified Cassava Starches were used as potential inhibitor for carbon steel corrosion and proved as efficient inhibitor for MS corrosion in 200 mg L⁻¹ NaCl [33]. EIS, PDP, FTIR, Gravimetric analysis reveals the corrosion rate of 0.06 mg cm⁻² h⁻¹ (30°C) and inhibition efficiency of 96.30 at 60°C at 400 ppm (30°C) [34]. For carbon steel corrosion, Hydroxyethyl Cellulose and surfactants applied in 1M HCl solution. Various corrosion monitoring techniques such as EIS, Quantum Chemical Analysis showed the good agreement for the potential of inhibitor [35]. Eddy et al (2011) showed using gravimetric analysis that the corrosion rate 0.000197 gcm⁻¹ at 303 K at 0.5 gl⁻¹ conc. of inhibitor [36]. They proposed the synergistic effect and found 6453% *I* in 0.5 g/L concentration at 300 K for MS corrosion by using (AL) anogessus Leocarpus gum [37]. Eddy (2012) and co-workers reported the Daniella Oliverri (DO) gum exudates as potential corrosion inhibitor on MS (0.1 M HCl) and found that do follows the Langmuir adsorption isotherm [38]. WL measurement suggest that inhibitor molecules follow the Langmuir and Freundlich model [39]. Natural polysaccharide namely Polyacrylamide compound with Okra mucilage exhibited optimum inhibition efficiency (96.6%) in 100 ppm concentration at room temperature [40]. Natural polysaccharide namely hydroxypropyl cellulose, glucose and Gellan gum evaluated as corrosion protection of cast iron. EIS shows that hydroxypropyl cellulose shows optimum % inhibition at room temperature [41]. PDP and WL analysis reveals the mixed nature of Guar gum at its optimum concentration [42]. Pipeline steel corrosion protection monitoring by techniques like PDP, FTIR, EIS and found mixed nature of inhibitor [43]. SEM analysis shows the

protective layer of xanthum gum on a MS surface [44]. CMC proved as effective inhibitor for MS corrosion in electrolytic media as per WL, HE, TG analysis [45]. Synergistic effect between KX (KBr, KI, KCl) and CMC exhibited effective corrosion resistance [46]. SEM analysis shows the synergistic protective layer of CMC and zinc ion onto carbon steel [47]. EDS analysis shows the modified chemical composition onto the carbon steel surface [48]. DFT calculation applied to determine inhibition property of synergism (HEC & KI) [49]. TS and DPMP act synergistically towards metal protection proved by FTIR and other analysis [50]. Surface analysis like SEM, XPS, FTIR, exhibited the barrier on metal surface of zinc ion, phosphonic acid and pectin [51]. SEM, FTIR analysis shows the inhibitory action of pectin enhanced by using it with grafted polymer [52]. EIS analysis proved the chitosan as efficient inhibitor for MS in corrosive media [53]. ATC based conjugated polymer act as efficient mixed type towards MS corrosion [54]. Nanogels (chitosan grafted) act as mixed nature towards MS corrosion inhibitor [55]. Surface analysis like EDS, XRD shows the protective layer deposited onto MS surface [56]. CCBA and CMCUGA synergistic make chitosan as potential corrosion inhibitor [57]. Techniques like AFM, XRD, EDS, EIS applied OFC as corrosion inhibitor [58]. The molecular structure, ferrous metals and media, techniques applied, nature of inhibitors and outcomes of the research depicted in Table 1.

Table 1. The molecular structure, ferrous metals and media, techniques applied, nature of inhibitors and outcomes of the research.

SN	Structure of Inhibitor	Metal & Electrolytic Media and nature of inhibitor	Technique Used	Salient Features	Ref.
1	<p>hydroxypropyl methylcellulose</p>	MS/ 0.5 M H ₂ SO ₄ / Mixed Type/ Freundlich model	WL, EIS, PDP, OCP, QCC, DFT	HPMC has been applied as potential corrosion inhibitor for MS corrosion in aggressive solution. HPMC follows Freundlich adsorption isotherm and its mixed type nature has been reported. According to EIS analysis HPMC exhibited 91.18 % <i>I</i> when applied with KI i.e. synergistic effect.	24

2	<p>Guar gum</p>	CS/ 1 M H ₂ SO ₄ / Mixed Type/ Langmuir model	WL	Guar gum applied as potential corrosion inhibitor for CS in corrosive solution (M. Abdullah 2004) and reported that it follows Langmuir adsorption isotherm. WL shown the surface coverage (θ) of 0.939 in 1500 ppm concentration of inhibitor	25
3	<p>Amylopectin</p>	MS/ 0.1 M H ₂ SO ₄ / Anodic/ Langmuir model	EIS, PDP, WL,	M. Mobin et al (2011) applied various technique like WL, PDP, DEM, where weight loss reveals the 67.41 % inhibition efficiency in 500 ppm concentration at 30°C of starch and surfactants. ΔG adsorption value -35.54 KJmol ⁻¹ observed at 30°C when starch applied with CTAB	26
4	<p>Gum Acacia and surfactants namely CTAB and SDBS</p> <p>CTAB</p> <p>SDBS</p>	MS/ 0.1 M H ₂ SO ₄ / Mixed Type/ Freundlich adsorption isotherm	WL, SEM, AFM	Synergistic effect of Gum Acacia and surfactants namely CTAB and SDBA used as corrosion inhibitor for mild steel in corrosive solution (0.1 M H ₂ SO ₄). Analysis performed at temperature ranging from 30°C to 60°C	27

5	<p>Xanthum gum</p>	MS/ 1 M HCl/ Mixed/ Langmuir model	WL, GA, PDP, EIS, QCC, SEM, UV-VS	Synergistic effect of Xanthum gum with surfactants was applied as corrosion inhibitor. 74.24 % IE obtained with XG at 1000 ppm at 30°C. Technique such as UV-VIS, SEM, EIS and DFT calculation applied for inhibition analysis	28
6	<p>gum arabic</p>	CS/ 1 M HCl/ Mixed/ Langmuir model	WL, SEM, AFM, UV- VIS, FTIR, EIS, GA, PDP	UV-VIS, AFM, SEM, FTIR and EIS technique applied to check efficiency of Plantago (polysaccharide) for carbon steel corrosion in acidic medium (1M HCl). -250 to +250 mV applied for electrochemical analysis (ppp) and found 86.11 IE at 400 ppm concentration	29
7	<p>pectin</p>	MS/ 0.5 M HCl/ Mixed Type	OCP, WL, SEM, PDP, EIS	EIS, SEM, PDP, WL analysis reveals that mixed type nature of pectin for MS in corrosive solution. Corrosion rate of 0.062 mgcm ⁻² h ⁻² and inhibition efficiency of 90.3 obtained at 2 g/L amount of inhibitor	30

8	<p>carboxymethyl cellulose</p> <p>cellulose</p>	MS/ 2 M H ₂ SO ₄ / Mixed/ Langmuir model	WL	Analysis suggest the dubinin-radushkevich and Langmuir adsorption isotherm of CMC at 30°C to 60°C and 64.8 inhibition efficiency as per weight loss analysis	31
9	<p>Hydroxyethylcellulose</p>	Carbon Steel/ 3.5% NaCl/ Mixed Type/ Langmuir model	OCP, QCC, EIS, SEM, DFT, PDP	Reported methods suggest the potential property of HEC towards CS and follows Langmuir model	32
10	<p>carboxymethylated starch</p> <p>cassava starch</p>	CS/ 0.05 M HCl	WL, DFT, XPS, EIS	Modified Cassava Starches used as potential inhibitor for carbon steel corrosion and proved as efficient inhibitor for MS corrosion in 200 mg L ⁻¹ NaCl	33

11	<p>chitosan</p> <p>arabinogalactan</p>	CS/ 1 M HCl/ Mixed Type/ Langmuir model	WL, GA, SEM PDP, OCP, QCC, DFT, AFM, UV-VS, EIS, MCS, AFM	EIS, PDP, FTIR, Gravimetric analysis reveals the corrosion rate of $0.06 \text{ mg cm}^{-2} \text{ h}^{-1}$ (30°C) and inhibition efficiency of 96.30 at 60°C at 400 ppm (30°C)	34
12	<p>Hydroxyethylcellulose</p>	CS/ 1 M HCl/ Mixed Type/ Langmuir model	PDP, UV- VIS, WL, EDX, AFM, QCC, OCP, SEM, EIS	For carbon steel corrosion, Hydroxyethyl Cellulose and surfactants applied in 1M HCl solution. Various corrosion monitoring techniques such as EIS, Quantum Chemical Analysis shown the good agreement for the potential of inhibitor	35
13	<p>Guar gum</p>	MS/ 0.1 M HCl/ Mixed/ Langmuir model	WL, EIS, PDP	Gravimetric analysis shows the corrosion rate $0.000197 \text{ g cm}^{-1}$ at 303 K at 0.5 g l^{-1} conc. Of inhibitor	36

14	<p>SUCROSE</p>	MS/ 0.1 M HCl/ Langmuir model	GCMS, FTIR, WL	Eddy et al (2011) proposed the synergistic effect and found 6453% I in 0.5 g/L concentration at 300 K for MS corrosion by using (AL) anogessus Leocarpus gum	37
15	<p>SUCROSE</p>	MS/ 0.1 M HCl/ Langmuir model	GA, GCMS, FTIR, WL	Eddy (2012) and coworkers reported the Daniella Oliverri (DO) gum exudates as potential corrosion inhibitor on MS (0.1 M HCl) and found that do follows the Langmuir adsorption isotherm	38
16	<p>arabinogalactan</p> <p>Guar gum</p>	MS/ 2 M HCl/ Langmuir and Freundlich model	GA, GM, TM, GCMS, WL	WL measurement suggest that inhibitor molecules follows Langmuir and Freundlich model	39

17	<p>Structure of O-g-PAM.</p> <p>Okra mucilage</p>	MS// 0.5 M H ₂ SO ₄ / Cathodic/ Langmuir model	GA, WL, OCP, SEM, EIS, XRD, FTIR, PDP	Natural polysaccharide namely Polyacrylamide compound with Okra mucilage exhibited optimum inhibition efficiency (96.6%) in 100 ppm concentration at room temperature	40
18	<p>gellan gum</p>	Cast Iron/ 1 M HCl/ Mixed / Langmuir and Freundlich model	WL, PDP, OCP, SEM, XRD, EIS	Natural polysaccharide namely hydroxypropyl cellulose, glucose and Gellan gum evaluated as corrosion protection of cast iron. EIS shows that hydroxypropyl cellulose shows optimum % inhibition at room temperature	41

19	<p style="text-align: center;">Guar gum</p> <p style="text-align: center;">gum arabic</p>	CS (L-52 grade)/ 1 M H ₂ SO ₄ containing NaCl/ Mixed nature	PDP, WL	PDP and WL analysis reveals the mixed nature of Guar gum at its optimum concentration	42
20	<p style="text-align: center;">gum arabic</p>	Pipeline steel (API 5L X42)/1 M HCl/ Mixed type	PDP, FTIR, EIS	Pipeline steel corrosion protection monitoring by techniques like PDP, FTIR, EIS and found mixed nature of inhibitor	43

21	<p>Xanthan gum and Xanthan gum-polyacrylamide conjugate</p> <p>Xanthan gum</p>	MS/ 15% HCl/ Mixed type	PDP, SEM, EIS, WL	SEM analysis shows the protective layer of xanthan gum on MS surface	44
22	<p>Carboxymethyl cellulose</p> <p>carboxymethyl cellulose</p>	MS/ 2 M H ₂ SO ₄	WL, HE, TG	CMC proved as effective inhibitor for MS corrosion in electrolytic media as per WL, HE, TG analysis	45
23	<p>carboxymethyl cellulose</p>	MS (AISI 1005 grade)/ 2 M H ₂ SO ₄	WL, HE	Synergistic effect between KX(KBr, KI, KCl) and CMC exhibited effective corrosion resistance	46
24	<p>CMC-Zn²⁺</p> <p>cellulose</p>	Carbon steel/ Ground water (pH 11)	EIS, SEM, WL	SEM analysis shows the synergistic protective layer of CMC and zinc ion onto carbon steel	47

25	<p>Hydroxyethylcellulose</p>	CS (1018 grade)/ 3.5% NaCl/ Mixed type	SEM, DFT, EIS, EFM, PDP, EDS,	EDS analysis shows the modified chemical composition onto carbon steel surface	48
26	<p>Hydroxyethylcellulose</p>	MS/ 0.5 M H ₂ SO ₄ / Mixed type	EIS, DFT, WL, PDP	DFT calculation applied to determine inhibition property of synergism (HEC & KI)	49
27	<p>tapioca starch</p>	MS/ 1 N HCl/ Mixed type	PDP, WL, EIS, FTIR	TS and DPMP act synergistically towards metal protection proved by FTIR and other analysis	50
28	<p>pectin</p>	Carbon steel/ 60 ppm Cl ⁻ / Mixed type	SEM, WL, XPS, EIS, FTIR	Surface analysis like SEM, XPS, FTIR, exhibited the barrier on metal surface of zinc ion, phosphonic acid and pectin	51
29	<p>pectin</p>	MS/ 3.5% NaCl/ Mixed (Cathodic mainly)	WL, EDS, TEM, TGA	SEM, FTIR analysis shows the inhibitory action of pectin enhanced by using it with grafted polymer	52
30	<p>chitosan</p>	MS/ 0.1 M HCl/ Mixed type	WL, SEM, PDP, EIS	EIS analysis proved the chitosan as efficient inhibitor for MS in corrosive media	53

31	chitosan	MS/ 0.5 M H ₂ SO ₄ / Mixed type	PDP, SEM, EIS	ATC based conjugated polymer act as efficient mixed type towards MS corrosion	54
32	chitosan	MS/ 1 M HCl/ Mixed	PDP, EIS	Nanogels (chitosan grafted) act as mixed nature towards MS corrosion inhibitor	55
33	chitosan	MS/ 0.1 N HCl/ Cathodic type	XRD, PDP, SEM, FTIR, EIS, EDS	Surface analysis like EDS, XRD shows the protective layer deposited onto MS surface	56
34	chitosan	MS/ NaCl 2%	Fluidization	CCBA and CMCUGA synergistic make chitosan as potential corrosion inhibitor	57
35	chitosan	MS/ 1 M HCl/ Mixed type	AFM, PDP, XRD, EDS, EIS, SEM	Techniques like AFM, XRD, EDS, EIS applied OFC as corrosion inhibitor	58

2.2 Corrosion inhibition of non-ferrous materials

Gravimetric analysis on aluminium in aggressive media of xanthum gum suggest that it follows the Temkin model [59]. Corrosion inhibition on aluminium in H₂SO₄ medium was evaluated by using Ficustricopoda gum (FP gum) at 0.5 g/L concentration. FP gum shows optimum inhibition i.e. 85.80 % [60]. Ficusbenjamina (FB) gum used and exhibited surface coverage of 0.875 at 0.5 g/L concentration [61]. Gum Arabic based research work has been published for corrosion inhibitor for Al and found effective inhibition property [62]. 0.5 M H₂SO₄ corrosive solution applied for corrosion inhibition

of aluminum by applying techniques such as DFT and WL [63]. Corrosion inhibition on AA6061 alloy studied using tapioca starch in natural saline water where EIS study reveals the 96.00% inhibition efficiency at 1000 ppm and ΔG 30.469 KJmol⁻¹ value suggest the mixed type nature of the inhibitor [64]. Gum Arabic (GA) treated and tested as potential corrosion inhibitor on aluminium corrosion inhibition in 1 M NaOH by various parameters like hydrogen evolution, adsorption, kinetics, gravimetric etc. Thermometric analysis reveals the % inhibition of 75.86 at 0.5 g/L amount of inhibitor [65]. S.A. Umoren and coworkers (2008) reveals that dacroylesedulis exudates gum shows % inhibition of 42.0 at 5 g/L concentration (30 °C temperature) [66]. Researchers reported the CMC as mixed type inhibitor as per WL analysis [67]. Analysis like CV, EIS and WL applied for Al & Al-Si alloys corrosion at 0.1 M NaOH and find efficient towards corrosion inhibition [68]. Scientists proved PA as efficient inhibitor by applying HE and WL techniques [69]. WL measurement suggest the good inhibition property of PA which follows Langmuir model [70]. Chitosan studied by applying PDP, DFT, WL, EFM, EIS techniques as Cu corrosion inhibitor and reported as mixed type nature [71]. Various techniques like EIS, FTIR, TGA, SEM, PDP were applied and reported the mixed type behaviour of chitosan [72]. Various techniques applied and result reveals the mixed type inhibition through the polysaccharides [73]. The molecular structure, ferrous metals and media, techniques applied, nature of inhibitors and outcomes of the research summarized in Table 2.

Table 2. The molecular structure, non-ferrous metals and media, techniques applied, nature of inhibitors and outcomes of the research.

SN	Structure of Inhibitor	Metal, Electrolytic Media and nature of inhibitor	Technique Used	Outcomes	Ref.
1	<p>Xanthum gum</p>	Aluminium/ 0.5 M HCl/ Mixed Type/ Temkin model	WL, PDP, OCP, ECP	Gravimetric analysis on Al in aggressive media of xanthum gum suggest that it follows the Temkin model	59

2	<p>SUCROSE</p>	Aluminum/ 0.01 M H ₂ SO ₄ / Langmuir model	WL, GCMS	Corrosion inhibition on aluminum in H ₂ SO ₄ medium was evaluated by using Ficustricopoda gum (FP gum) at 0.5 g/L concentration. FP gum shows optimum inhibition i.e. 85.80.	60
3	<p>SUCROSE</p>	Aluminum/ 0.1 M H ₂ SO ₄ / FDR adsorption model	WL, GCMS, FTIR	Ficusbenjamina (FB) gum used and exhibited surface coverage of 0.875 at 0.5 g/L concentration	61
4	<p>gum arabic</p>	Aluminium/ 0.1 M HCl/ Langmuir model	WL, GA, QCC, FTIR, GCMS	Gum Arabic based research work has been published for corrosion inhibitor for Al and found effective inhibition property	62
5	<p>hydroxypropyl methylcellulose</p>	Aluminium/ 0.5 M H ₂ SO ₄ / Cathodic/ Freundlich model	WL, EIS, QCC, DFT, PDP, OCP	0.5 M H ₂ SO ₄ corrosive solution applied for corrosion inhibition of aluminum by applying techniques such as DFT and WL	63

6	<p>amylose</p> <p>amylopectin</p> <p>tapioca starch</p>	Aluminium and its Alloy/ HCl/ Mixed Type/ Langmuir model	WL, GA, PDP, LPR, EIS, SEM, EDS, OCP, FTIR	Corrosion inhibition on AA6061 alloy studied using tapioca starch in natural saline water where EIS study reveals the 96.00% inhibition efficiency at 1000 ppm and ΔG 30.469 KJmol ⁻¹ value suggest the mixed type nature of inhibitor	64
7	<p>arabinogalactan</p> <p>gum arabic</p>	Aluminium/ 0.1-2.5 M NaOH/ Langmuir and Freundlich model	GA, GM, TM, ES, PM	Gum Arabic (GA) treated and tested as potential corrosion inhibitor on aluminum corrosion inhibition in 1 M NaOH by various parameters like hydrogen evolution, adsorption, kinetics, gravimetric etc. Thermometric analysis reveals the % inhibition of 75.86 at 0.5 g/L amount of inhibitor	65

8	<p>arabinogalactan</p> <p>gum arabic</p> <p>Guar gum</p>	Aluminium/ 2 M HCl/ Temkin model	WL, TM	S. A. Umoren and coworkers (2008) reveals that dacrodesedulis exudates gum shows % inhibition of 42.0 at 5 g/L concentration (30°C temperature)	66
9	<p>carboxymethyl cellulose</p>	Al/ Ground water (pH 11)/ Mixed (cathodic basically)	SEM, EIS, WL, PDP	Researchers reported the CMC as mixed type inhibitor as per WL analysis	67
10		Al & Al-Si alloys/ 0.1 M NaOH/ Anodic	PDP, CV, EIS	Analysis like CV, EIS and WL applied for Al & Al-Si alloys corrosion at 0.1 M NaOH and find efficient towards corrosion inhibition	68

11	Pectic Acid	Al/ 4 M NaOH	HE, WL	Scientists proved PA as efficient inhibitor by applying HE and WL techniques	69
12	Pectic Acid	Al/ 4 M NaOH	HE, WL	WL measurement suggest the good inhibition property of PA which follows Langmuir model	70
13	Chitosan	Cu/ 0.5 M HCl/ Mixed type	PDP, DFT, WL, EFM, EIS	Chitosan studied by applying PDP, DFT, WL, EFM, EIS techniques as Cu corrosion inhibitor and reported as mixed type nature	71
14	Chitosan	304 steel/Cu sheets/ 2% acetic acid/ Mixed type	EIS, FTIR, TGA, SEM, PDP	Various techniques like EIS, FTIR, TGA, SEM, PDP applied and reported the mixed type behavior of chitosan	72
15	carrageenan alginate	H ₂ SO ₄ and HCl/Mixed Type/ Langmuir model	GA, WL, EIS, SEM, PDP, OCP, DFT, XPES, XRD, FTIR, AFM	Various techniques applied and result reveals the mixed type inhibition through the polysaccharides	73

3. Adsorption mechanism

Organic inhibitor molecules have been used in place of organic compounds such as phosphate, chromate, and arsenate over the past decades to prevent metal dilution in aqueous solutions [74]. Polysaccharides and their derivatives are non-polluting organic compounds that are used as effective corrosion inhibitors [50-54]. These organic materials in the corrosive solution are adsorbed onto the metal surface by physical force

(physisorption) or chemical bond (chemical adsorption). These organic inhibitors reduce their anodic resolution rate by covering the entire metal surface or preventing cathodic reaction by blocking the active site of the metal surface so that the metal surface is not damaged or degraded in any way [75]. In this way, the polymer is deposited on to the metal surface like a blocker, in which corrosive molecule cannot attack. The efficiency of corrosion inhibition of polysaccharides depends on different types of inhibitor molecules. Some molecules have a greater number of cyclic rings, some have functional groups and alkyl chain lengths, and some have sulfonate and carboxylic groups [76]. In addition to the bulky group in the inhibitor molecule, the presence of unshared electron pair and extended π bond makes the organic molecule as the efficient corrosion inhibitor. Inhibitor molecules that have ΔG values less than $-20 \text{ kJ / mol}^{-1}$ are physisorption and ΔG values up to $-40 \text{ kJ / mol}^{-1}$ are adjusted on the metal surface by chemical adsorption. The nature of the inhibitor representing the value of ΔG between these two is considered as mixed type [77-81]. Figs. 2 and 3 represents the proposed adsorption mechanism of chemisorption and physisorption, respectively.

Figure 2. Proposed chemisorption mechanism of polysaccharide.

Figure 3. Proposed physisorption mechanism of polysaccharide.

4. Further aspects

Polysaccharides based corrosion inhibitor suggests that most of the studies have been on mild steel / steel and aluminum metal. Mainly HCl, H₂SO₄ and NaCl have been frequently used as electrolytic media. But there has been almost no research on metal like Cu, Zn, Mg, Sn, Pb and their metal alloys as a corrosion inhibitor of Polysaccharides, on which research is yet to be done. Theoretical studies like MD simulation and DFT calculation applied in limited research papers, which is yet to be done. Electrolytic medium has been used in low concentration. While the behaviors of corrosion inhibitor in high concentration has been studied in few papers. Also, other media other than NaCl can be used for basic medium. In this way, there is still research into polysaccharides corrosion inhibitors is to be done.

Conclusion

Polysaccharides are polymers containing repeated units of carbohydrate sugar. These complex structures are very good corrosion inhibitors due to biodegradability, easy availability, cost effective, non-toxic, environment friendly properties. The cyclic rings, odd atoms and π electron densities present in them increase the efficiency, allowing them on to deposit above the metal surface. Some natural green synthetic biopolymer, mixed type inhibitors including composites of polysaccharides are described in this book

chapter. In addition to chemical and electrochemical analysis, computational studies such as DFT and MD simulations are also described in some recent research papers, which are included in this book chapter. Based on the properties of the analysis and the molecule, it would be fair to say that polysaccharide is a good alternative to toxic, expensive, and hazardous inhibitors.

Acknowledgement

Authors greatly acknowledge the Principal Govt. Digvijay Autonomous College, Rajnandgaon for providing basic facilities.

Abbreviations

WL	=	Weight loss
EIS	=	Electrochemical impedance spectroscopy
PDP	=	Potentiodynamic polarization
OCP	=	Open circuit potential
SEM	=	Scanning electron microscopy
EDS	=	Electron dispersion x-ray spectroscopy
QCC	=	Quantum chemical calculation
DFT	=	Density function theory,
XPES	=	X-ray photoelectron spectroscopy
MDS	=	Molecular dynamic simulation
XRD	=	X-ray diffraction
FTIR	=	Fourier transform infrared
AFM	=	Atomic force microscopy
EDXA	=	Energy dispersive x-ray analysis
GCMS	=	Gas chromatography mass spectrophotometer
HE	=	Hydrogen evolution
CTAB	=	Cetyl Trimethyl Ammonium Bromide

References

- [1] C. Verma, M.A. Quraishi, Thermodynamic, electrochemical and surface studies of dendrimers as effective corrosion inhibitors for mild steel in 1 M HCl, *Anal. Bioanal. Electrochem.* 8(1) (2016) 104-123.
- [2] S. Bourichi, Y.K. Rodi, M. El Azzouzi, Y. Kharbach, F.O. Chahdi, A. Aouniti, Inhibitive effect of new synthesized imidazopyridine derivatives for the mild steel corrosion in Hydrochloric acid medium, *J. Mater. Environ. Sci.* 8(5) (2017) 1696-1707.

- [3] E.S. Ferreira, C. Giacomelli, F.C. Giacomelli, A. Spinelli, Evaluation of the inhibitor effect of L-ascorbic acid on the corrosion of mild steel, *Mater. Chem. Phys.* 83(1) (2004) 129-134. <https://doi.org/10.1016/j.matchemphys.2003.09.020>
- [4] I. Sekine, Y. Nakahata, H. Tanabe, The corrosion inhibition of mild steel by ascorbic and folic acids, *Corros. Sci.* 28(10) (1988) 987-1001. [https://doi.org/10.1016/0010-938X\(88\)90016-9](https://doi.org/10.1016/0010-938X(88)90016-9)
- [5] L.R. Chauhan, G. Gunasekaran, Corrosion inhibition of mild steel by plant extract in dilute HCl medium, *Corros. Sci.* 49 (2007) 1143-1161. <https://doi.org/10.1016/j.corsci.2006.08.012>
- [6] X. Wang, Y. Gu, Q. Zhang, L. Xu, X. Li, Rose, gardenia, and solanumviolaceum extracts as inhibitors of steel corrosion, *Int. J. Electrochem. Sci.*, 14 (2019) 8405-8418. <https://doi.org/10.20964/2019.09.41>
- [7] S. Paul, I. Koley, Corrosion inhibition of carbon steel in acidic environment by papaya seed as green inhibitor, *J. Bio. Tribo. Corros.* 2 (2016) 6. <https://doi.org/10.1007/s40735-016-0035-2>
- [8] R. Anitha, S. Chitra, Corrosion resistance of cissusquadrangularis extracts on metal in aggressive medium: Gravimetric and surface examinations, *Rasayan J. Chem.* 12 (2019) 1326-1339. <https://doi.org/10.31788/RJC.2019.1235195>
- [9] N. Raghavendra, J. IshwaraBhat, An environmentally friendly approach towards mitigation of Al corrosion in hydrochloric acid by yellow colour ripe arecanut husk extract: Introducing potential and sustainable inhibitor for material protection, *J. Bio. Tribo. Corros.* 4 (2018). <https://doi.org/10.1007/s40735-017-0112-1>
- [10] A.K. Satapathy, G. Gunasekaran, S.C. Sahoo, K. Amit, P.V. Rodrigues, Corrosion inhibition by Justiciagendarussa plant extract in hydrochloric acid solution, *Corros. Sci.* 51 (2009) 2848-2856. <https://doi.org/10.1016/j.corsci.2009.08.016>
- [11] H. Mohammed, S.bt. Sobri, Corrosion inhibition studies of cashew nut (*Anacardiumoccidentale*) on carbon steel in 1.0 M hydrochloric acid environment, *Mater. Lett.* 229 (2018) 82-84. <https://doi.org/10.1016/j.matlet.2018.06.108>
- [12] E.S. Ferreira, C. Giacomelli, F.C. Giacomelli, A. Spinelli, Evaluation of the inhibitor effect of L-ascorbic acid on the corrosion of mild steel, *Mater. Chem. Phys.* 83 (2004) 129-134. <https://doi.org/10.1016/j.matchemphys.2003.09.020>
- [13] P.B. Raja, M.G. Sethuraman, Natural products as corrosion inhibitor for metals in corrosive media - A review, *Mater. Lett.* 62 (2008) 113-116. <https://doi.org/10.1016/j.matlet.2007.04.079>

- [14] M. Behzadnasab, S.M. Mirabedini, K. Kabiri, S. Jamali, Corrosion performance of epoxy coatings containing silane treated ZrO₂ nanoparticles on mild steel in 3.5% NaCl solution, *Corros. Sci.* 53 (2011) 89-98.
<https://doi.org/10.1016/j.corsci.2010.09.026>
- [15] X. Li, S. Deng, H. Fu, G. Mu, Inhibition effect of 6-benzylaminopurine on the corrosion of cold rolled steel in H₂SO₄ solution, *Corros. Sci.* 51 (2009) 620-634.
<https://doi.org/10.1016/j.corsci.2008.12.021>
- [16] W.H. Li, Q. He, S.T. Zhang, C.L. Pei, B.R. Hou, Some new triazole derivatives as inhibitors for mild steel corrosion in acidic medium, *J. Appl. Electrochem.* 38 (2008) 289-295. <https://doi.org/10.1007/s10800-007-9437-7>
- [17] A. Popova, E. Sokolova, S. Raicheva, M. Christov, AC and DC study of the temperature effect on mild steel corrosion in acid media in the presence of benzimidazole derivatives, *Corros. Sci.* 45 (2003) 33-58.
[https://doi.org/10.1016/S0010-938X\(02\)00072-0](https://doi.org/10.1016/S0010-938X(02)00072-0)
- [18] A. Döner, R. Solmaz, M. Özcan, G. Kardaş, Experimental and theoretical studies of thiazoles as corrosion inhibitors for mild steel in sulphuric acid solution, *Corros. Sci.* 53 (2011) 2902-2913. <https://doi.org/10.1016/j.corsci.2011.05.027>
- [19] R. Solmaz, G. Kardaş, M. Çulha, B. Yazici, M. Erbil, Investigation of adsorption and inhibitive effect of 2-mercaptothiazoline on corrosion of mild steel in hydrochloric acid media, *Electrochim. Acta.* 53 (2008) 5941-5952.
<https://doi.org/10.1016/j.electacta.2008.03.055>
- [20] H. Ashassi-Sorkhabi, B. Shaabani, D. Seifzadeh, Corrosion inhibition of mild steel by some schiff base compounds in hydrochloric acid, *Appl. Surf. Sci.* 239 (2005) 154-164. <https://doi.org/10.1016/j.apsusc.2004.05.143>
- [21] M. Lebrini, M. Lagrenée, H. Vezin, L. Gengembre, F. Bentiss, Electrochemical and quantum chemical studies of new thiadiazole derivatives adsorption on mild steel in normal hydrochloric acid medium, *Corros. Sci.* (2005) 47, 485-505.
<https://doi.org/10.1016/j.corsci.2004.06.001>
- [22] M. Palomar-Pardavé, M. Romero-Romo, H. Herrera-Hernández, M.A. Abreu-Quijano, N.V. Likhanova, J. Uruchurtu, J.M. Juárez-García, Influence of the alkyl chain length of 2 amino 5 alkyl 1,3,4thiadiazole compounds on the corrosion inhibition of steel immersed in sulfuric acid solutions, *Corros. Sci.* 54 (2012) 231-243.
<https://doi.org/10.1016/j.corsci.2011.09.020>

- [23] A.S. Begum, J. Mallika, P. Gayathri, Corrosion inhibition property of some 1, 3, 4-thiadiazolines on mild steel in acidic medium, *E. J. Chem.* 7 (2010) 185-197.
<https://doi.org/10.1155/2010/623298>
- [24] I.O. Arukalam, Durability and synergistic effects of KI on the acidcorrosion inhibition of MS by hydroxypropyl methylcellulose, *Carbohydr. Polymer.* 112 (2014) 291-9. <https://doi.org/10.1016/j.carbpol.2014.05.071>
- [25] M. Abdallah, Guar Gum as Corrosion Inhibitor for Carbon Steel in Sulfuric Acid Solutions, *Port. ElectrochimicaActa* (2003) 161-175.
<https://doi.org/10.4152/pea.200402161>
- [26] M. Mobin, M.A. Khan, M. Parveen, Inhibition of MS Corrosion in Acidic Medium Using Starch and Surfactants Additives, *J. Appl. Polymer Sci.* 121(3) (2011) 1558-1565. <https://doi.org/10.1002/app.33714>
- [27] M. Mobin, M.A. Khan, Investigation on the Adsorption and Corrosion Inhibition Behavior of Gum Acacia and Synergistic Surfactants Additives on MS in 0.1 M H₂SO₄, *J. Disper. Sci. Technol.* 34(11) (2013) 1496-1506.
<https://doi.org/10.1080/01932691.2012.751031>
- [28] M. Mobin, M. Rizvi, Inhibitory effect of xanthan gum and synergistic surfactant additives for MS corrosion in 1 M HCl, *Carbohydr. Polymer.* 136 (2016) 384-393.
<https://doi.org/10.1016/j.carbpol.2015.09.027>
- [29] M. Mobin, M. Rizvi, Polysaccharide from Plantagoas a Green Corrosion Inhibitor for Carbon Steel in 1M HCl Solution, *Carbohydr. Polymer.* 160 (2017) 172-183.
<https://doi.org/10.1016/j.carbpol.2016.12.056>
- [30] M.V. Fiori-Bimbi, P.E. Alvarez, H. Vaca, C.A. Gervasi, Corrosion inhibition of MS in HCl solution by pectin, *Corros. Sci.* 92 (2015) 192-199.
<https://doi.org/10.1016/j.corsci.2014.12.002>
- [31] M.M. Solomon, S.A. Umoren, I.I. Udosoro, A.P. Udoh, Inhibitive and adsorption behaviour of carboxymethyl cellulose on MS corrosion in sulphuric acid solution, *Corros. Sci.* 52(4) (2010) 1317-1325. <https://doi.org/10.1016/j.corsci.2009.11.041>
- [32] M.N. EL-Haddad, Hydroxyethylcellulose used as an eco-friendly inhibitor for 1018 c- steel corrosion in 3.5% NaCl solution, *Carbohydr. Polymer.* 112 (2014) 595-602.
<https://doi.org/10.1016/j.carbpol.2014.06.032>
- [33] M. Bello, N. Ochoa, V. Balsamo, F. López-Carrasquero, S. Coll, A. Monsalve, G. González, Modified cassava starches as corrosion inhibitors of carbon steel: An

- electrochemical and morphological approach, *Carbohydr. Polymer*. 82(3) (2010) 561-568. <https://doi.org/10.1016/j.carbpol.2010.05.019>
- [34] M. Mobin, M. Rizvi, L.O. Olasunkanmi, E.E. Ebenso, Biopolymer from tragacanth gum as a green corrosion inhibitor for carbon steel in 1 M HCl solution, *ACS Omega*. 2(7) (2018) 3997–4008. <https://doi.org/10.1021/acsomega.7b00436>
- [35] M. Mobin, M. Rizvi, Adsorption and corrosion inhibition behavior of hydroxyethylcellulose and synergistic surfactants additives for carbon steel in 1 M HCl, *Carbohydr. Polymer* 156 (2017) 202-214. <https://doi.org/10.1016/j.carbpol.2016.08.066>
- [36] N.O. Eddy, P. Ameh, C.E. Gimba, E.E. Ebenso, Chemical information from gums of *Ficus platyphylla* gum and its corrosion inhibition potential for MS in 0.1 M HCl, *Int. J. Electrochem. Sci.* 7 (2012) 5677 - 5691.
- [37] N.O. Eddy, P. Ameh, C.E. Gimba, E.E. Ebenso, GCMS studies on *Anogessus Leocarpus* (Al) gum and their corrosion inhibition potential for MS in 0.1 M HCl, *Int. J. Electrochem. Sci.* 6 (2011) 5815 - 5829.
- [38] N.O. Eddy, A.O. Odiongenyi, P.O. Ameh, E.E. Ebenso, Corrosion inhibition potential of *Daniella Oliverri* Gum exudate for MS in acidic medium, *Int. J. Electrochem. Sci.*, 7 (2012) 7425 - 7439.
- [39] P.O. Ameh, Adsorption and Inhibitive Properties of *Khaya ivorensis* Gum for the Corrosion of MS in HCl, *Int. J. Mod. Chem.* 2(1) (2012) 28-40. <https://doi.org/10.1007/s11164-013-1117-0>
- [40] S. Banerjee, V. Srivastava, M.M. Singh, Chemically modified natural polysaccharide as green corrosion inhibitor for MS in acidic medium, *Corros. Sci.* 59 (2012) 35-41. <https://doi.org/10.1016/j.corsci.2012.02.009>
- [41] V. Rajeswari, D. Kesavan, M. Gopiraman, P. Viswanathamurthi, Physicochemical studies of glucose, gellan gum, and hydroxypropyl cellulose-Inhibition of cast iron corrosion, *Carbohydr. Polymer*. 95(1) (2013) 288- 294. <https://doi.org/10.1016/j.carbpol.2013.02.069>
- [42] M. Abdallah, Guar gum as corrosion inhibitor for carbon steel in sulfuric acid solutions, *Port. Electrochimica Acta* 22 (2004) 161-175. <https://doi.org/10.4152/pea.200402161>
- [43] H. Bentrach, Y. Rahali, A. Chala, Gum Arabic as an eco-friendly inhibitor for API 5L X42 pipeline steel in HCl medium, *Corros. Sci.* 82 (2014) 426-431. <https://doi.org/10.1016/j.corsci.2013.12.018>

- [44] A. Biswas, S. Pal, G. Udayabhanu, Experimental and theoretical studies of xanthan gum and its graftco-polymer as corrosion inhibitor for MS in 15% HCl, *Appl. Surf. Sci.* 353 (2015) 173-183. <https://doi.org/10.1016/j.apsusc.2015.06.128>
- [45] M.M. Solomon, S.A. Umoren, I.I. Udosoro, A.P. Udoh, Inhibitive and adsorption behaviour of carboxymethyl cellulose on MS corrosion in sulphuric acid solution, *Corros. Sci.* 52(4) (2010) 1317-1325. <https://doi.org/10.1016/j.corsci.2009.11.041>
- [46] S.A. Umoren, U.F. Ekanem, Inhibition of MS corrosion in H₂SO₄ using exudate gum from *pachylobusedulis* and synergistic potassium halide additives, *Chem. Eng. Comm.* 197(10) (2010) 1339-1356. <https://doi.org/10.1080/00986441003626086>
- [47] N. Manimaran, S. Rajendran, M. Manivannan, J.A. Thangakani, A.S. Prabha, Corrosion inhibition by carboxymethyl cellulose, *Eur. Chem. Bull.* 2(7) (2013) 494-498.
- [48] M.N. EL-Haddad, Hydroxyethylcellulose used as an eco-friendly inhibitor for 1018 c- steel corrosion in 3.5% NaCl solution, *Carbohydr. Polymer.* 112 (2014) 595-602. <https://doi.org/10.1016/j.carbpol.2014.06.032>
- [49] I.O. Arukalam, I.C. Madufor, O. Ogbobe, E.E. Oguzie, Inhibition of mild steel corrosion in sulphuric acid medium by hydroxyethyl cellulose, *Chem. Eng. Commun.* 202(1) (2014) 112-122. <https://doi.org/10.1080/00986445.2013.838158>
- [50] T. Brindha, J. Mallika, V.S. Moorthy, Synergistic effect between starch and substituted piperidin-4-one on the corrosion inhibition of MS in acidic medium, *J. Mater. Environ. Sci.* 6(1) (2015) 191-200.
- [51] M. Prabakaran, S. Ramesh , V. Periasamy, B. Sreedhar, The corrosion inhibition performance of pectin with propyl phosphonic acid and Zn²⁺ for corrosion control of carbon steel in aqueous solution, *Res. Chem. Intermed.* 41 (2015) <https://doi.org/10.1007/s11164-014-1558-0> 4649-4671.
- [52] R. Geethanjali, A.A.F. Sabirneeza, S. Subhashini, Water-soluble and biodegradable pectin-grafted polyacrylamide and pectin-grafted polyacrylic acid: electrochemical investigation of corrosion-inhibition behaviour on MS in 3.5% NaCl media, *Indian J. Mater. Sci.* (2014) 356075. <https://doi.org/10.1155/2014/356075>
- [53] S.A. Umoren, M.J. Banera, T. Alonso-Garcia, C.A. Gervasi, M.V. Miri'fico, Inhibition of MS corrosion in HCl solution using chitosan, *Cellulose.* 20 (2013) 2529-2545. <https://doi.org/10.1007/s10570-013-0021-5>

- [54] A.M. Fekry, R.R. Mohamed, Acetyl thiourea chitosan as an eco-friendly inhibitor for MS in sulphuric acid medium, *Electrochim. Acta.* 55(6) (2010) 1933-1939. <https://doi.org/10.1016/j.electacta.2009.11.011>
- [55] A.M. Atta, G.A. El-Mahdy, H.A. Al-Lohedan, A.R.O. Ezzat, Synthesis of nonionic amphiphilic chitosan nanoparticles for active corrosion protection of steel, *J. Mol. Liq.* 211 (2015) 315-323. <https://doi.org/10.1016/j.molliq.2015.07.035>
- [56] S. John, A. Joseph, A.J. Jose, B. Narayana, Enhancement of corrosion protection of MS by chitosan/ZnO nanoparticle composite membranes, *Prog. Org. Coatings.* 84 (2015) 28-34. <https://doi.org/10.1016/j.porgcoat.2015.02.005>
- [57] S.H.D. Koesoemo, R. Ruriyanti, L.S. Anggara, Application chitosan derivatives as inhibitor corrosion on steel with fluidization method, *J. Chem. Pharm. Res.* 7 (2015) 260-267.
- [58] Y. Sangeetha, S. Meenakshi, C.S. Sundaram, Corrosion mitigation of N-(2-hydroxy-3-trimethyl ammonium)propylchitosan chloride as inhibitor on MS, *Int. J. Biol. Macromol.* 72 (2015) 1244- 1249. <https://doi.org/10.1016/j.ijbiomac.2014.10.044>
- [59] I.O. Arukalam, N.T. Ijomah, S.C. Nwanonenyi, H.C. Obasi, B.C. Aharanwa, P.I. Anyanwu, Studies on acid corrosion of aluminium by a naturally occurring polymer (Xanthan gum), *Int. J. Sci. Eng. Res.* 5(3) (2014) 663-673.
- [60] N.O. Eddy, P.O. Ameh, M.Y. Gwarzo, I.J. Okop, S.N. Dodo, Physicochemical study and corrosion inhibition potential of ficus tricopoda for aluminium in acidic medium, *Port. Electrochim. Acta.* 31(2) (2013) 79-93. <https://doi.org/10.4152/pea.201302079>
- [61] N.O. Eddy, P.O. Ameh, A.O. Odiongenyi, Physicochemical characterization and corrosion inhibition potential of ficus benjamina (fb) gum for aluminum in 0.1 M H₂SO₄, *Port. Electrochim. Acta.* 32(3) (2014) 183-197. <https://doi.org/10.4152/pea.201403183>
- [62] N.O. Eddy, U.J. Ibok, P.O. Ameh, N.O. Alobi, M.M. Sambo, Adsorption and quantum chemical studies on the inhibition of the corrosion of aluminum in HCl by *Gloriosasuperba* (GS) Gum, *Chem. Eng. Comm.* 201(10) (2014) 1360-1383. <https://doi.org/10.1080/00986445.2013.809000>
- [63] N.O. Eddy, P.O. Ameh, O. Danclementino, A. Odiongenyi, Adsorption and chemical studies on the inhibition of the corrosion of aluminium in hydrochloric acid by *commiphora africana* gum, *Int. J. Chem. Mater. Environ. Res.* 1(1) (2014) 16-28.

- [64] R. Rosliza, W.B.W. Nik, Improvement of corrosion resistance of AA6061 alloy by tapioca starch in seawater, *Curr. Appl. Phys.* 10(1) (2010) 221-229.
<https://doi.org/10.1016/j.cap.2009.05.027>
- [65] S.A. Umoren, I.B. Obot, E.E. Ebenso, P.C. Okafor, O. Ogbobe, E.E. Oguzie, Gum arabic as a potential corrosion inhibitor for aluminium in alkaline medium and its adsorption characteristics, *Anti-Corros. Meth. Mater.* 53(5) (2006) 277-282.
<https://doi.org/10.1108/00035590610692554>
- [66] S.A. Umoren, I.B. Obot, E.E. Ebenso, N. Obi-Egbedi, Studies on the inhibitive effect of exudate gum from dacrodydesedulison the acid corrosion of aluminium, *Port. Electrochim. Acta* (2008) 199-209. <https://doi.org/10.4152/pea.200802199>
- [67] R. Kalaivani, P.T. Arasu, S. Rajendran, Inhibitive nature of Carboxymethylcellulose with Zn^{2+} ion, *Chem. Sci. Trans.* 2(4) (2013) 1352-1357.
<https://doi.org/10.7598/cst2013.618>
- [68] S. Eid, M. Abdallah, E.M. Kamar, A.Y. El-Etre, Corrosion inhibition of aluminum and aluminum silicon alloys in sodium hydroxide solutions by methyl cellulose, *J. Mater. Environ. Sci.* 6(3) (2015) 892-901.
- [69] I. Zaaferany, Corrosion inhibition of aluminum in aqueous alkaline solutions by alginate and pectate water-soluble natural polymer anionic polyelectrolytes, *Port. Electrochim. Acta.* 30(6) (2012) 419-426. <https://doi.org/10.4152/pea.201206419>
- [70] R.M. Hassan, I.A. Zaaferany, Kinetics of corrosion inhibition of aluminum in acidic media by water-soluble natural polymeric pectates as anionic polyelectrolyte inhibitors, *Mater. (Basel)* 6(6) (2013) 2436-2451. <https://doi.org/10.3390/ma6062436>
- [71] M.N. El-Haddad, Chitosan as a green inhibitor for copper corrosion in acidic medium, *Int. J. Biol. Macromol.* 55 (2013) 142- 149.
<https://doi.org/10.1016/j.ijbiomac.2012.12.044>
- [72] M.L Li, R.H. Li, J. Xu, X. Han, T.Y. Yao, J. Wang, Thiocarbohydrazide-modified chitosan as anticorrosion and metal ion adsorbent, *J. Appl. Polym. Sci.* 131(17) (2014) 40671. <https://doi.org/10.1002/app.40671>
- [73] S.A. Umoren1, U.M. Eduok, Application of carbohydrate polymers as corrosion inhibitors for metal substrates in different media: A review, *Carbohydr. Polymer.* 140 (2016) 314-341. <https://doi.org/10.1016/j.carbpol.2015.12.038>
- [74] J. Aljourani, K. Raeissi, M.A. Golozar, Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution, *Corros. Sci.* 51 (2009) 1836-1843. <https://doi.org/10.1016/j.corsci.2009.05.011>

- [75] A. Popova, E. Sokolova, S. Raicheva, M. Christov, AC and DC study of the temperature effect on mild steel corrosion in acid media in the presence of benzimidazole derivatives, *Corros. Sci.* 45 (2003) 33-58.
[https://doi.org/10.1016/S0010-938X\(02\)00072-0](https://doi.org/10.1016/S0010-938X(02)00072-0)
- [76] H. Cang, Z. Fei, H. Xiao, J. Huang, Q. Xu, Inhibition effect of reed leaves extract on steel in hydrochloric acid and sulphuric acid solutions, *Int. J. Electrochem. Sci.* 7 (2012) 8869-8882.
- [77] C. Kamal, M.G. Sethuraman, *Spirulina platensis* - A novel green inhibitor for acid corrosion of mild steel, *Arab. J. Chem.* 5 (2012) 155-161.
<https://doi.org/10.1016/j.arabjc.2010.08.006>
- [78] M. Bouklah, B. Hammouti, M. Lagrenée, F. Bentiss, Thermodynamic properties of 2,5-bis(4-methoxyphenyl)-1,3,4-oxadiazole as a corrosion inhibitor for mild steel in normal sulfuric acid medium, *Corros. Sci.* 48 (2006) 2831-2842.
<https://doi.org/10.1016/j.corsci.2005.08.019>
- [79] F.B. Mainier, R.de.M.B.e. Silva, Evaluation of corrosion inhibitors in acid medium, *Anti Corros. Meth. Mater.* 62 (2015) 241-245. <https://doi.org/10.1108/ACMM-12-2013-1329>
- [80] M. Hosseini, S.F.L. Mertens, M. Ghorbani, M.R. Arshadi, Asymmetrical Schiff bases as inhibitors of mild steel corrosion in sulphuric acid media, *Mater. Chem. Phys.* 78 (2003) 800-808. [https://doi.org/10.1016/S0254-0584\(02\)00390-5](https://doi.org/10.1016/S0254-0584(02)00390-5)
- [81] J. Zhou, X. Niu, Y. Cui, Z. Wang, J. Wang, R. Wang, Study on the film forming mechanism, corrosion inhibition effect and synergistic action of two different inhibitors on copper surface chemical mechanical polishing for GLSI, *Appl. Surf. Sci.* 505 (2019) 144507. <https://doi.org/10.1016/j.apsusc.2019.144507>