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REVIEW

Use of natural gums as green corrosion inhibitors: an overview

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Abstract Corrosion of metals and its alloys employed in service is an inescapable but a controllable process. One of the practical methods for controlling the impact of corrosion of metals and alloys especially in aqueous environments is by using corrosion inhibitors which are composed mainly of organic or inorganic substances. However, the toxicity of organic and inorganic corrosion inhibitors to the environment and humans has compelled the search for safer corrosion inhibitors called 'green corrosion' inhibitor due to their properties like non-toxicity, biodegradability, and low cost. The use of natural gums as environmentally safe corrosion inhibitor for metal and alloys has in recent times received tremendous attention by several researchers. Also quantitative structure activity relationship approach has been used to establish the correlations between a number of quantum chemical parameters and the molecular structures of some gum extracts major components. This approach has aided in understanding the component of the gum extracts responsible for imparting the inhibition effect since there are several components of the gum which could act in synergy to inhibit the metal corrosion. This review paper presents an overview of works published on natural gums as green corrosion inhibitors. It also discusses the use of computational chemistry tools in understanding the inhibition mechanism of gum extracts components which is often difficult to determine using experimental means.

Keywords Corrosion · Gum · Metals · Corrosion inhibitor · Acid · Computer modelling

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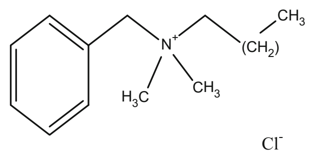
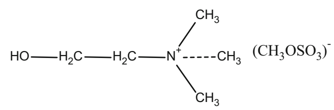
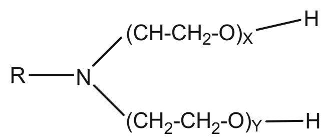
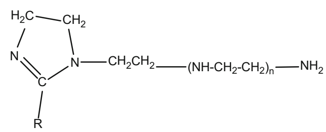
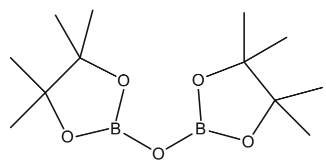
Introduction

Corrosion is the degradation of a metal either by direct chemical or electrochemical reaction when in contact with aqueous corrosive surroundings. It is an endless and costly problem, often difficult to eradicate completely. It is a foremost problem that has safety, conservation and economic impacts in various chemical, motorized, metallurgical, natural and medical engineering applications and more particularly in the design of a much more varied number of mechanical parts which equally vary in size, functionality and useful lifespan [1–3]. Corrosion can cause life-threatening damage to metal and alloy structures causing financial punishment in terms of renovation, replacement, product losses, safety and environmental pollution [4]. Metal degradation may result in elevated productivity loss arising from the malfunctioning of the corroded instruments and contamination of main industrial products (e.g. chemical products) by the aqueous corrosion products [5]. Leakage of products leads to loss in efficiency. If the corrosion contaminated materials are left untreated, the industry may have to face equipment failure [6]. Due to these harmful effects, corrosion is an unattractive observable fact that must be prevented [4–8]. Prevention would be more realistic and practicable than complete eradication.

Table 1 Synthetic inhibitors with their market value brand names

S. no.	Synthetic corrosion inhibitor	Common structure	Brand name	Use
1.	Benzyl chloride quaternary compounds		Alpha 1018, 1038, 1458,1505, 3013, 3444	Used to formulate corrosion preventives
2.	Diethylsulphate quaternary compounds		Alpha 1080	Used to make corrosion preventives
3.	Amine ethoxylates compounds		C1815	Used in oil- and water-soluble solution
4.	Imidazoline compounds		Alpha 1153, 1158	Used to formulate corrosion inhibitor
5.	Organic boron compounds		Alpha 3220	Used to formulate corrosion inhibitor for oxygen, carbon dioxide, hydrogen sulphide, mineral acid and dissolved salts

Corrosion inhibitors

A corrosion inhibitor is a substance which when added in ppm concentrations to a corrosive environment minimizes or prevents corrosion [9]. These substances can adsorb both physically and chemically at the metal-solution interface and obstruct the contact surface between the metal and the corrosive agents [10–13]. A good corrosion inhibitor should have a readily adsorption capacity on the metal surface through either physiosorption or chemisorption processes [14]. Due to their industrial importance, most corrosion inhibitors have been synthesized from economical raw materials or chosen from compounds containing heteroatom in their aromatic or long carbon chain. Over the years, significant efforts have been deployed to discover appropriate corrosion inhibitors of natural starting point in various corrosive media [15–18]. In acid media, nitrogen-based materials and their derivatives, sulphur-containing compounds, aldehydes, thioaldehydes, acetylenic compounds, and various alkaloids, for example, papaverine, strychnine, quinine and nicotine are used as inhibitors. In neutral media, benzoate, nitrite, chromate and phosphate act as good inhibitors. Inhibitors decrease or prevent the reaction of the metal with the media.

Properties of corrosion inhibitors

(i) Strong adsorption onto metal surface
(ii) Increasing or decreasing the anodic and/or cathodic reaction
(iii) Decreasing the diffusion rate for reactants to the surface of the metal
(iv) Decreasing the electrical resistance of the metal surface.

Numerous factors including price tag and quantity, easy availability and most importantly safety to environment and its species need to be considered when choosing an inhibitor. Inhibitors of organic origin can be divided it into two major parts.

1. Synthetic/Organic inhibitors 2. Green inhibitors (Table 1).

Synthetic/Organic inhibitors

Organic inhibitors generally have hetero atoms. O, N, S and P are found to have higher basicity and electron-donor abilities and thus act as corrosion inhibitor. O, N, S and P are the active centres for the process of adsorption on the metal surface. Synthetic inhibitors are synthesized in the laboratory to serve as a capable alternate for the natural one. The use of inhibitors is one of the best options of protecting metals against corrosion. Several inhibitors in use are also synthesized from cheap raw material or selected from compounds having heteroatom's in their aromatic or long-chain carbon system. However, most of these inhibitors are noxious to the atmosphere. This has encouraged the search for green corrosion inhibitors [19].

Green inhibitors

Green corrosion inhibitors are eco-friendly and do not contain heavy metals or other poisonous compounds. An inhibitor is a material (or a mixture of substances) added in a very low concentration to treat the surface of a metal that is uncovered to a corrosive environment that terminates or diminishes the corrosion of a metal. These are also known as site-blocking elements or adsorption site blockers, due to their adsorptive properties [20–22]. The term "green inhibitor" or "eco-friendly inhibitor" refers to the substances that have biocompatibility with the natural environment (Table 2).

Natural gums as corrosion inhibitors

Gums obtained from plants are solids consisting of mixtures of polysaccharides (carbohydrates) which are either water soluble or absorb water and swell up to form a gel or jelly when placed in water. They are insoluble in oils or organic solvents such as hydrocarbons, ether and alcohol. The mixtures are often complex and on hydrolysis yield simple sugars such as arabinose, galactose, mannose and glucuronic acid. Some gums are formed by exudation, usually from the stem of a tree but in a few cases from the root. The exudation is often considered to be a pathological response to injury of the plant, either accidental or caused by insect borers, or by deliberate injury ("tapping"). Seed gums are those isolated from the endosperm portion of some seeds. The uses of the gums discussed in this report are elaborated in the corrosion inhibition sections concerned, but they embrace food, pharmaceutical and miscellaneous technical applications. In the food industry, advantage is taken of their thickening, stabilizing, emulsifying and suspending properties, and they are employed in a very wide range of products, both foods and drinks. In the pharmaceutical industry, they are used as binding agents in tablets and as suspending and emulsifying agents in creams and lotions, some have specific applications in the dental and medical fields. We are reporting some gums which are reported as effective corrosion inhibitors.

According to *Eddy* et al, Gums have been found to be good corrosion inhibitors due to the following reasons [33]

(1) Through their functional group, they form complexes with metal ions and on the metal surfaces.
(2) Gum metal complexes occupy a large surface area, there by blanketing the surface and shielding the metal from corrosive agents present in the solution.
(3) The presence of arbinogalactan, sucrose, oligosaccharides, polysaccharides and glucoprotein since these compounds contain oxygen and nitrogen atoms which are the centres of adsorption.
(4) Most gums have COOH functional groups, which can increase the contribution of electron or charge

Table 2 Green corrosion inhibitors used for corrosion inhibition for different metals

S. no.	Metal	Inhibitor source	Active ingredient	Ref.
1.	Steel	*Emblica officinalis*	–	[23]
2.	Steel	*Terminalia bellerica*	–	[23]
3.	Steel	Eucalyptus oil	Monomtrene 1,8-cineole	[24]
4.	Aluminium	*Azardirachta indica* and *carica papaya*	–	[25]
5.	C-steel, Ni, Zn	Lawsonia extract (Henna)	Lawsone (2-hydroxy-1,4-napthoquinone resin and tannin, coumarine, gallic, acid and sterols)	[26]
6.	Mild steel	*Musa sapientum* peels (Banana peels)	–	[27]
7.	Mild steel	Garcinia kola seed	Primary and secondary amines Unsaturated fatty acids and Biflavnone	[28]
8.	Steel	*Hibiscus sabdariffa (Calyx extract) in* 1MH_2SO_4 and 2 M HCl solutions, Stock 10–50 %	Molecular protonated organic species in the extract. Ascorbic acid, amino acids, flavonoids, pigments and carotene	[29]
9.	Al, steel	Aqueous extract of tobacco plant and its parts	Nicotine	[30]
10.	Al	*Prosopis cineraria* (khejari)	–	[31]
11.	Al	Tannin beetroot	–	[32]
12.	Al	Saponin	–	[32]

transfer and hence facilitate inhibition through adsorption.

(5) Most gums are less toxic, green and eco-friendly.

In this review article, we are trying to summarize the research that has been done so far by using various gums as green corrosion inhibitors.

Gum arabic

Gum arabic (GA) is the oldest and popular in all natural gums. It is dried, orange-brown coloured solid, which breaks with glassy fraction and gummy exudates obtained from various species of Acacia trees of the Leguminosae family. The potential of Gum arabic as a corrosion inhibitor for aluminium in alkaline medium has been investigated. The inhibition of aluminium corrosion by Gum arabic was reported to be due to the presence of arabinogalactan, oligosaccharides, polysaccharides and glucoproteins [34, 35]. Corrosion inhibition potential of GA was reported for mild steel and aluminium in H_2SO_4 solution by the use of weight loss and thermometric techniques. Inhibition efficiency increases with increase in concentration of the inhibitor; the inhibitor GA was found to obey the Temkin adsorption isotherm for mild steel and Aluminium. Chemical adsorption was reported for mild steel corrosion and physical adsorption was reported for aluminium. On the basis of thermodynamics studies, the adsorption of GA onto the metal surface was spontaneous and GA is better corrosion inhibitor for Al than Mild steel [36]. The inhibitive effect of the gum exudates from Acacia Seyal Var. Seyal has been reported as a good anodic inhibitor for drinking water using potentiodynamic polarization and EIS techniques. Obtained results show that the % inhibition increases with the increase in concentration of the gum inhibitor and inhibition efficiency was insensitive towards temperature rise. Its mechanism attributed to the chemisorptions [37].

Gum Acacia was reported as a good corrosion inhibitor in HCl and H_2SO_4 solution for mild steel corrosion. Obtained results show that corrosion rates of MS in HCl and H_2SO_4 decreased with increasing concentration of Gum Acacia. Weight loss, Hydrogen evolution and polarization methods were used to propose the potential applicability of Gum Acacia as a green corrosion inhibitor for Mild steel in acidic medium [38]. GA was also reported as good inhibitor for Mild steel in H_2SO_4 solution with halide additives, and obtained results show that inhibition efficiency increases with the increase in concentration of inhibitor, and halide additive enhances the effect of inhibition and this mechanism found to obey the Temkin adsorption isotherm [39]. Inhibition of Aluminium corrosion was reported in alkaline solution by the gum arabic [40]. Corrosion inhibition of Al in NaOH in the presence of GA and iodide ion was studied by using weight loss and hydrogen evolution techniques. Obtained results show that GA inhibits the Al corrosion in NaOH medium with potassium halide additives and inhibition efficiency increases with the increase in concentration and temperature. The adsorption of GA, KI and (GA + KI) followed the Temkin adsorption [41].

Locust bean gum

This gum was also known as a carob gum and was extracted from the seed of carob tree. It consists mainly of galactomannan-type polysaccharides, with a galactose:mannose ratio of about 1:4. LB gum investigated for corrosion inhibition potential for carbon steel corrosion marked steel 39, 44 and B500 in H_2SO_4 solution. Electrochemical and potentiodynamic polarization methods were used for inhibition testing which revealed that carob gum shows their inhibition effect on Steel 39 in acidic medium with the addition of NaCl [42].

Guar gum

Guar gum comes from the endosperm of the seed of the legume plant *Cyamopsis tetragonolobus.* Guar gum is prepared by first drying the pods in sunlight, then manually separating from the seeds. Chemically, guar gum is a polysaccharide composed of the sugars galactose and mannose. The backbone is a linear chain of 1,4-linked mannose residues to which galactose residues are 1,6-linked at every second mannose, forming short side branches [43].

The first ever corrosion inhibition potential of gums was reported by Abdulla on carbon steel corrosion in 1 M H_2SO_4 solution by using weight loss and electrochemical methods. PDP method was used to investigate its inhibition efficiency of Guar gum on the pitting corrosion of carbon steel in 1 M H_2SO_4 solution containing NaCl and its results revealed that Guar Gum increases resistance for pitting corrosion.

Weight loss method result revealed that inhibition efficiency increases with increase in concentration, and electrochemical method results also supported the same thing and showed that Guar gum acts as a mixed-type inhibitor and all data were well applicable into Langmuir adsorption isotherm [44].

Albizia gum

Albizia gum derived from trees of the genus *Albizia* is formed as round elongated bars of variable size and colour ranging from yellow to dark brown [45]. *Albizia zygia* gum is of particular interest because of their safe use, high solubility in water and high molecular size. The gas chromatography-mass spectroscopy (GCMS) spectra of the gum point out the attendance of hetero-atoms like nitrogen, sulphur and oxygen in their structure [46].

A. Zygia gum has been found to be a good corrosion inhibitor for mild steel in H_2SO_4 solution by using the weight loss, Gasometric and FTIR methods. The obtained results show that percentage (%) inhibition efficiency was decreased with rise in temperature but increases with the increase of concentration and its mechanism fits into the physical adsorption [47].

Excudated gum Raphia hookeri

Universal Name is Wine Palm; it originates in valley swamps throughout Western and Central Africa. Suckering palm, with extremely long, (to 12 m) dark green, pinnate leaves, rigid leaflets, and a trunk up to 10 m high. RH gum has been found to be an effective corrosion inhibitor for aluminium in HCl solution on temperature range between 30 and 60 °C by using the thermometric and weight loss techniques. Obtained results from weight loss techniques show that corrosion rate decreases by the increase in concentration which means that inhibition efficiency increases with the increase of concentration. Thermometric method result revealed that strong adsorption was noted at higher concentration of RH gum as by decrease in maximum temperature which means that its inhibition efficiency decreases by the rise of temperature, and the adsorption process was found to obey the Temkin adsorption [48].

RH gum reported good corrosion inhibitor for Aluminium corrosion with the addition of halide ions in acidic medium by the use of weight loss, hydrogen evolution and thermometric techniques and obtained results show that inhibition efficiency increases with the increase in concentration and it is significantly improved by the addition of halide ions, inhibition efficiency decreases by the increase in temperature. It is simply proposing the physical adsorption mechanism and found to obey the Freundlich, Langmuir and Temkin adsorption isotherm [49].

Dacroydes edulis

Dacryodes edulis or Safou is a fruit tree from Africa, generally called African or bus pear or plum, Safou, bush butter tree, or butter fruit. The gummy exudates of this tree are cheap and locally available. *Dacroydes edulis gum* was reported as cheap and environmentally safe inhibitor for aluminium corrosion in acidic medium by the use of weight loss and thermometric methods at 30–60 °C. Temkim adsorption isotherm was applied [50].

Exudated gum Pachylobus edulis (PE)

Common name of Pear safou or African plum. The gummy exudates production from this plant is contributed as a green corrosion inhibitor or environmentally friendly manner. In the following studies, the investigation shows that the corrosion inhibiting effect of exudated gums from *Pachylobus edulis* (PE) was reported for Mild steel in H_2SO_4 solution with the potassium halide additives by the use of hydrogen evolution and thermometric methods at 30-60 °C temperature range. Obtained results show that corrosion rate decreases with the increase in concentration but increases with the rise in the temperature. Synergistic effect increased the inhibition efficiency in the presence of potassium halides in the order KI > KBr > KCl. Mechanism found to obey the Temkin adsorption isotherm [51].

The anti-corrosive effect of PE Gum with the halide ions was reported on Al corrosion in acidic medium by the use of weight loss method on 30-60 °C temperature range. Obtained results show that inhibition efficiency increases with the increase of concentration of inhibitor and it enhances by the addition of halide ions and decreases with the temperature rise. Mechanism follows the physical adsorption which obeyed the Temkin adsorption isotherm [52].

Ficus glumosa gum

African rock fig is a small to medium-sized tree, usually growing 5–10 m tall, though it may become a large tree reaching 24 metres and 50 cm in diameter. It has been reported as good inhibitor for the Mild steel corrosion in H_2SO_4 solution by the weight loss, thermometric and SEM techniques. Obtained results show that inhibition efficiency increases with the rise in temperature and concentration. The mechanism of inhibition effect was due to chemical adsorption and obeyed the Langmuir adsorption model [53].

Commiphora kestingii gum

Common names for this gum are Fula-fulfulde (Fulani), Mbiji, Nupe etc., usually growing 2–5 m tall and found mostly in rocks with the low altitude dry woodlands from Togo to Nigeria. It has been reported as a corrosion inhibitor for aluminium corrosion in acidic medium by the use of GCMS, FTIR (Fourier transformed infrared spectroscopy) Techniques. Obtained results show the increase in inhibition efficiency with the rise of temperature and concentration that simply applies the chemical adsorption mechanism. Freundlich, Temkin and Florry-Huggins adsorption reported [54].

Ficus Benjamina gum

Commonly known as the weeping fig, Benjamin's fig or ficus tree, FB Gum is found to inhibit the corrosion of Al in tetraoxosulphate (VI) acid by the use of weight loss and FTIR techniques. Obtained results show that inhibition efficiency increases with the rise of temperature and concentration that follows the mechanism of chemical adsorption and support the Frumkin, Dubinin–Radushikevich adsorption model [55].

Anogessius leocarpus gum (AL gum)

AL Gum was reported as effective inhibitor for MS corrosion with the addition of potassium halide ions in HCl solution by the use of experimentally weight loss and geometric method obtained results revealed that inhibition efficiency increases with the increase in concentration and decreases with the temperature and its follow the physical adsorption mechanism and fit into the Langmuir adsorption isotherm [56].

Commiphora pendunculata gum

This gum was investigated as an effective inhibitor for Aluminium alloy in HCl solution by the use of weight loss and thermometric methods. Obtained results show that corrosion inhibition efficiency of CP gum increases with increase in concentration but decreases in the rise of temperature and it totally fits into physical adsorption mechanism and found to obey the Langmuir adsorption isotherm [57].

Ficus platyphylla gum

This gum was reported as a good corrosion inhibitor for mild steel in HCl solution by using weight loss, FTIR and gasometric techniques. Obtained results show that the inhibition efficiency increases with the increase in concentration but decreases with the temperature rise, and adsorption of FP gum on mild steel surface is exothermic and spontaneous which favours the physical adsorption and is found to obey the Langmuir adsorption isotherm [58].

Ficus tricopoda gum

This gum was reported as a corrosion inhibitor for Al in acidic medium by using FTIR, GCMS techniques. Obtained results show that initial adsorption of FT gum shows the physical adsorption and it is succeeded by the chemical adsorption mechanism so it represents both types of mechanism and found to obey the Langmuir adsorption isotherm [59].

Gloriosa superba gum

This gum was reported as a corrosion inhibitor for Al in HCl medium by using FTIR, GCMS techniques. Obtained results show that initial adsorption of FT gum shows the physical adsorption and it is succeeded by the chemical adsorption mechanism so it represents both types of mechanism and is found to obey the Langmuir adsorption isotherm [60].

Khaya ivorensis gum

Khaya ivorensis gum exudates (KI) was reported as an effective corrosion inhibitor for the corrosion of mild steel in HCl medium by the use of weight loss, gasometric and thermometric techniques. Obtained results show that inhibition efficiencies of the gum were found to increase with the increasing concentration of inhibitors and decrease with the increase in temperature, this phenomenon supports physical adsorption mechanism, and adsorption was exothermic, spontaneous and best described by the Langmuir adsorption isotherm [61].

Ficus thonningii gum

Ficus thonningii gum was reported as an effective corrosion inhibitor for aluminium corrosion in the solution of HCl by the use of GCMS and FTIR spectrophotometer, respectively; the increase in concentration of inhibitor increases the inhibition efficiency for the Aluminium corrosion but inhibition efficiency decreases with the increase in temperature which was the symptom of physical adsorption and it follows the Langmuir adsorption isotherm [62].

Daniella olieverri gum

Daniella oliverra gum (DO-gum) was collected from full-grown stem of the plant throughout the dry season. The gum was collected by tapping. *Daniella olliverri* (DO) gum exudates were analysed and the results indicated that the gum is acidic, brownish in colour, ionic and highly soluble in water but insoluble in acetone, chloroform and ethanol. Corrosion inhibition potential of the gum was investigated using weight loss and FTIR methods. *Daniella oliverri* acted as an effective inhibitor for mild steel corrosion in HCl solution [63] (Table 3).

Molecular modelling of natural gum extracts components

The use of computer modelling in corrosion inhibitor studies have been recently reviewed [64, 65]. These

Table 3 Effects of using different gums as corrosion inhibitor and their effects on various parameters involved

Metal	Medium	Gum	Effect of temperature on corrosion inhibition efficiency		Effect of concentration on corrosion inhibition efficiency		Methods	Adsorption type	Ref.
			Inhibition efficiency	Temperature	Inhibition efficiency	Concentration			
Mild steel and Al	H_2SO_4	*Gum arabic*	Decrease	Rise in temperature	Increase	Increase	Weight Loss & Thermometric	Chemical adsorption in mild steel & physical adsorption in aluminium	[36]
Mild steel	Drinking water	*Acacia var seyal*	Insensitive for temperature effect		Increase	Increase	EIS, potentiodynamic polarization	Chemisorptions	[37]
Aluminium	NaoH + KI (potassium halide)	*Gum arabic*	Increase	Increase	Increase	Increase	Weight loss and hydrogen evolution	Temkin (chemisorption)	[41]
Carbon steel	H_2SO_4	*Guar gum*	Decrease	Increase	Increase	Increase	Weight loss, Tafel polarization	Langmuir	[44]
Mild steel	H_2SO_4	*Albizia zygia*	Decrease	Increase	Increase	Increase	FTIR, Thermometric	Physical adsorption	[46, 47]
Aluminium	HCl	*Raphia hookeri*	Decrease	Increase	Increase	Increase	Weight Loss & Thermometric	Temkin	[48]
Aluminium	HCl	*Raphia hookeri with halides additive*	Decrease	Increase	Increase	Increase	Weight Loss & Gasometric	Frumkin, Langmuir	[49]
Mild steel	H_2SO_4	*Pachylobus edulis with potassium halides*	Decrease	Increase	Increase	Increase	Hydrogen evolution and Thermometric	Temkin	[51]
Aluminium	Halide ions + HCl	*Pachylobus edulis*	Decrease	Increase	Increase	Increase	Weight Loss	Temkin	[52]
Mild steel	H_2SO_4	*Ficus glumosa*	Increase	Increase	Increase	Increase	Weight loss, hydrogen Evolution, Scanning electron microscopy	Langmuir (chemical adsorption)	[53]
Aluminium	H_2SO_4	*Ficus benjamin*	Decrease	Increase	Increase	Increase	Weight loss	Frumkin & Dubinin Radushkevich (chemical adsorption)	[54]
Aluminium	H_2SO_4	*Commiphora kestingii*	Increase	Increase	Increase	Increase	Weight loss & Scanning electron microscopy	Chemisorption, Multi layer adsorption	[55]
Al alloy	HCl	*Commiphora pendunculata*	Decrease	Increase	Increase	Increase	Gravimetric & Thermometric	Langmuir	[57]
Aluminium	H_2SO_4	*Ficus tricopoda*	Decrease	Increase	Increase	Increase	Weight loss, GCMS	Langmuir & frumkin	[59]
Aluminium	HCl	*Gloriosa superba*	Increase	Increase	Increase	Increase	FTIR & Gravimetric	Florry-Huggins, Parson &volmer	[60]
Mild steel	HCl	*Anogessius leocarpus + potassium halide additives*	Decrease	Increase	Increase	Increase	Weight loss & gasometric	Langmuir	[56]

Table 3 continued

Metal	Medium	Gum	Effect of temperature on corrosion inhibition efficiency		Effect of concentration on corrosion inhibition efficiency		Methods	Adsorption type	Ref.
			Inhibition efficiency	Temperature	Inhibition efficiency	Concentration			
Mild steel	HCl	*Ficus platyphylla*	Decrease	Increase	Increase	Increase	Gravimetric, FTIR,GCMS	Physical adsorption	[58]
Mild steel	HCl	*Khaya ivorensis*	Decrease	Increase	Increase	Increase	Weight loss & gasometric	Langmuir	[61]
Aluminium	HCl	*Ficus thonningii*	Decrease	Increase	Increase	Increase	Weight loss & gasometric	Langmuir	[62]

reviews were mainly focused on organic corrosion inhibitors. Although there are some reports on the use of molecular modelling in understanding the mechanism of corrosion inhibition of plant extracts major components on metals and alloys [66–68], only one report to the best of the authors' knowledge exists on quantum chemical modelling of major components of natural gums [69]. Quantum modelling were performed to illustrate the adsorption process of some specific components of two oleo-gum resin exudates extracted from *Ferula asafoetida* and *Dorema ammoniacum* on mild steel corrosion in acidic media [69].

According to the authors owing to the complex chemical composition of the oleo-gum resin exudates investigated, it was very difficult to assign the inhibitive effect of the gums to a particular constituent compound experimentally, since some of the gum constituents including tannins, organic and amino acids, alkaloids, proteins, flavonoids and organic pigments and their acid hydrolysis products are known to exhibit inhibiting action. However, quantum chemical calculations were employed to explain the difference in behaviour of these two oleo-gum resins by carrying out molecular modelling of some major constituents making up these oleo-gum resin exudates. The quantum chemical parameters most relevant for their inhibition potentials on steel surface such as molecules E_{HOMO} (the energy of the highest occupied molecular orbital), E_{LUMO} (the energy of the lowest unoccupied molecular orbital), ΔE (energy gap) and μ (dipole moment) were computed and correlated to their inhibition effect. Frontier orbital such as HOMO orbitals and LUMO orbitals were plotted to understand the active sites responsible for adsorption of the gum molecules on steel. According to quantum chemical calculation results from the study, the differences in behaviour of two oleo-gum resins can be related to the differences in constituent compounds of oleo-gum resins. Most of constituent compounds of oleo-gum resin *F.assa-foetida* related to constituent compounds of oleo-gum resin D. ammoniacum have higher E_{HOMO}, lower E_{LUMO} and consequently lower ΔE. It seems that these conditions according to the authors cause the increase in the inhibition efficiency of oleo-gum resin F. assa-foetida when compared to constituent compounds of oleo-gum resin D. ammoniacum (Figs. 1, 2).

Conclusion

The use of natural gums for corrosion inhibitors for metals and alloys for various applications is attractive because they are economical, renewable materials, easily available, non-hazardous, potentially biodegradable and also biocompatible with the natural environment. We conclude that the use of gums as an alternative corrosion inhibitor for costly corrosion inhibitors should be pursued and more researches should be carried out on other gums and also on other corrosive environments like CO_2, H_2S, and NaCl which hve great impact on metals in the oil and gas industries. This paradigm shift will create chemicals which are beneficial to the environment and human beings on one hand and also prevent losses due to the effect of corrosion on the other hand.

Future outlook

The application of molecular dynamics simulations to study the adsorption mechanism between gums major components on metal surfaces is recommended for future researches in this area. There is no report in the literature on the atomistic simulation of gum components on metal

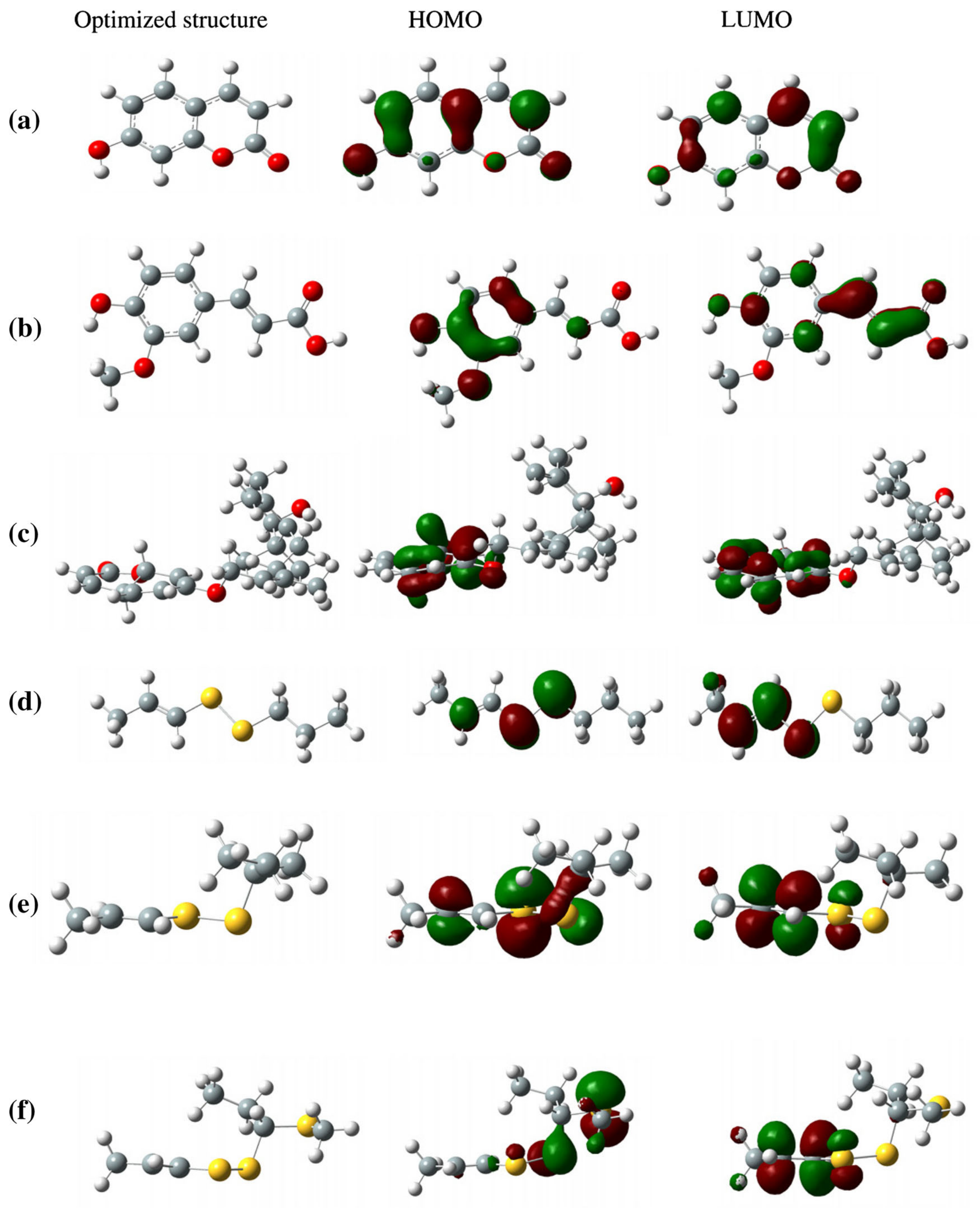


Fig. 1 Molecular structure, molecular orbital plots of some major constituents of F. assa-foetida; **a** Umbelliferone, **b** ferulic acid, **c** farnesiferol, **d** 1-propenyl propyl disulphide, **e** (R)-2-butyl-1-propenyl disulphide and **f** 1(1-methylthiopropyl) 1-propenyl disulphide [52]

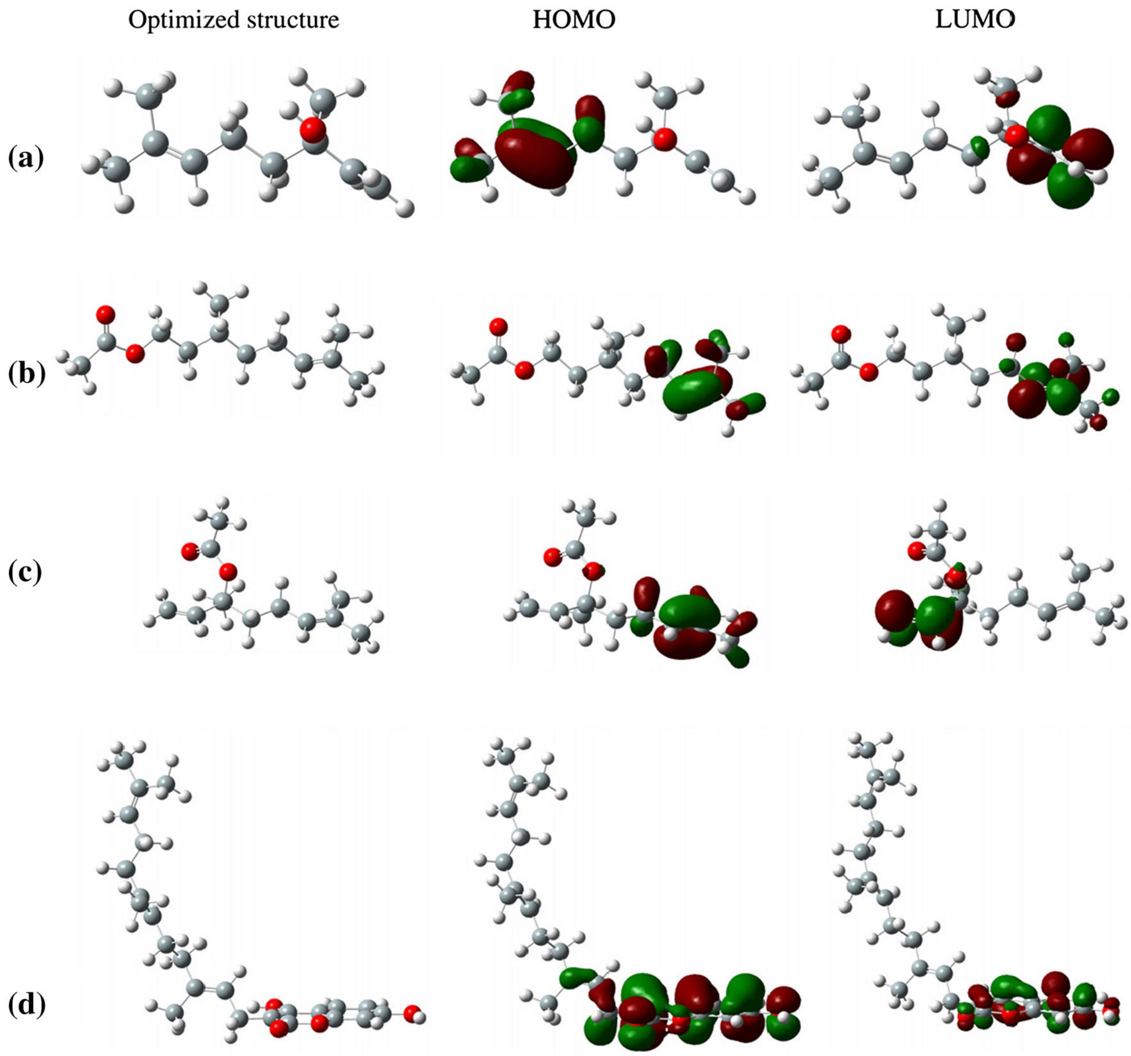


Fig. 2 Molecular structure, molecular orbital plots of some major constituents of D. ammoniacum; **a** linalool, **b** linalyl acetate, **c** citronellyl acetate and **d** Ammoresinol [52]

surfaces and will be useful to understand the inhibition effects of the gums at the molecular level.

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