Chapter

Green Corrosion Inhibitory Potentials of Cassava Plant (*Manihot esculenta* Crantz) Extract Nanoparticles (CPENPs) in Coatings for Oil and Gas Pipeline

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Abstract

Internal and external corrosion affects oil and gas pipelines and were discussed in this chapter. Corrosion inhibitors are one of the methods that can be used to achieve corrosion control and prevention. The main discussion in this chapter was the use of cassava plant (*Manihot esculenta* Crantz) extract nanoparticles (CPENPs) as an additive in coatings to serve as a green corrosion inhibitor for oil and gas pipeline. Trace elements, such as O, Si, Ca, K, Fe and S, which are hetero-atoms, have been identified in CPENPs. Elements like Si and Ca would also improve the strength of coatings as well as reduce corrosion rate of coated metals. It has also been revealed that CPENPs is composed of the following compounds SiO_2, $CaCO_3$, $Ca_2(SO_4)_2H_2O$ and $CaC_2O_4(H_2O)$, which would help in improving the mechanical properties of alloys, composites and coatings. SiO_2 if added to coatings will improve the coating hardness, while the presence of $CaCO_3$ in coatings will form a precipitate that will serve as a protective film on the surface of the metal, thereby protecting the metal from corrosion. The nature of bond and organic compounds that exist in the CPENPs was also discussed.

Keywords: cassava extract, coatings, corrosion, green inhibitor, nanoparticles

1. Introduction

Corrosion is the main problem affecting pipelines in the oil and gas industry. Internal corrosion in oil and gas pipelines is primarily caused by the presence of water together with acid gases or sulphate reducing bacteria. It can be categorized into three: sweet corrosion, sour corrosion and microbiological influenced corrosion. Conversely, in external corrosion the medium in the surrounding reacts with the outer side of metal pipelines thereby causing certain damages. The soil is complex three-phased system, which makes it a conductor to the metal pipelines. The application of coating and inhibitors has help to solve the corrosion problem. Coatings may be applied alone or may be used with other common methods such as proper material selection, cathode protection (CP) and application of inhibitors to modify the corrosive environment. In time past different types of coatings have been used such as bituminous enamels, asphalt mastic, liquid epoxies and phenolics, extruded plastic coatings, fusion-bonded epoxy (FBE), tape, three-layer polyolefin, wax coatings, high performance composite coating system, low temperature application technology for powder, thermotite flow assurance coating technology and paint. Paints used as coatings have been very effective in reducing the rate of corrosion in many industries, where various metals which are prone to corrosion are put into use.

Use of some inhibitors, such as chromate, has been banned because of toxicity and the environmental hazards they create [1]. Hence there is a need to make use of environmental friendly, non-toxic extracts of naturally occurring plant materials as corrosion inhibitors also known as green corrosion inhibitors. Extracts of plant materials contain a wide variety of organic compounds. Most of them contain hetero-atoms such as phosphorous, nitrogen, sulfur and oxygen. These atoms coordinate with the corroding metal atom (their ions) through their electrons [2]. Hence protective films are formed on the metal surface, thereby preventing corrosion. Some of the green corrosion inhibitors that have been used in the past are extracts from Aloe vera, Banana Plant juice, Mango, Orange, Passion fruit, Cashew peels, Tobacco leaves, etc. [1, 3–5].

Most researches have led to the discovering of new green corrosion inhibitors from plant part, but few of them have provided practical coating application that can solve corrosion problems as it applies to the oil and gas pipelines. Most green corrosion inhibitors are extracted from food and fruit items e.g. mango, orange, cassava, cashew juice and bitter leaf, which endangers food security. It is important to identify the ingredients and nature of bonds that exist in plant part extracts which are responsible for inhibiting corrosion in steel pipelines. The use of liquid extracts from cassava tuber has been studied in the past for corrosion resistance for mild steel [6]. But there is still work to be done in the area of coating using green inhibitors. Cassava plant solid extract (bark, stem and leaf) which are dumped in the environment can be processed and used as corrosion inhibitors because of the presence of heteroatoms and organic compounds, which are responsible for inhibiting corrosion. Processing of cassava plant solid extract (bark, leaf and stem) into green corrosion inhibitor will provide a cheap, environmental friendly and efficient green corrosion inhibitor and also solve environmental challenges caused by the dumped cassava waste.

Paint which usually consists of four main parts includes: solvents, pigments, binders and additives. In dealing with anticorrosive paints, red oxide pigment helps in preventing corrosion. The additives in paints play vital roles, which include the inhibition of corrosion. Inhibitors can be added to paint and it must be non-toxic, environmentally friendly, cost effective and readily available. Extracts from plants have been used as green inhibitors in the past and have been found to be environmentally friendly, non-toxic, cheap and abundantly available. Nanoparticles can improve paint property because of the unique properties of nanoparticles. Incorporating nanosize additives in paint provide effective barrier performance, reduce the amount of holiday in paint and also enhance the integrity and durability of paint, since the fine particles dispersed in paint can fill cavities. Research has been carried out on cassava starch as green corrosion inhibitors [7], and the modification of cassava starches as potential corrosion inhibitors has been used on steel rods. Cassava starch which is sometimes a waste in most cassava processing plants, shows considerable improvement in the prevention of corrosion [8].

This current chapter seeks to discuss green corrosion inhibitory potentials of cassava plant (*Manihot esculenta Crantz*) extract nanoparticles (CPENPs) in coatings for oil and gas pipeline. The cassava extract to be considered here are the bark, leaf and stem, which is usually dumped all over the environment as waste. Cassava extract can be processed into nanoparticles and added into coatings as a green corrosion inhibitor.

2. Corrosion problems in oil and gas pipeline

Corrosion is the main problem affecting oil and gas pipelines. Understanding the electro-chemical nature of corrosion was a major breakthrough, as shown in **Figure 1**, and this made it possible for corrosion to be mitigated, if electric current sufficient to offset the inherent corrosion current of a particular environment were caused to flow in the opposite direction. The applied direct current was termed "cathodic" protection because it made the pipe the cathode in a galvanic cell [10, 11]. The required current could be supplied by connecting a "sacrificial" anode (i.e., a metal with a higher oxidation potential than iron) in an electrical circuit where soil acted as the "electrolyte." Alternatively, commercial current could be directed to the pipe via an anode bed. The application of coating and inhibitors also help to solve the corrosion problem [10, 11].

2.1 Internal corrosion in pipeline

Internal corrosion in oil and gas pipelines is primarily caused by the presence of water together with acid gases (carbon dioxide or hydrogen sulphide) or sulphate reducing bacteria [12]. It can be divided into three broad categories:

- Sweet corrosion
- Sour corrosion
- Microbiological influenced corrosion (MIC)

2.2 External corrosion in pipeline

The medium in the surrounding reacts with the outer side of metal pipelines chemically, electrochemically and physically causing certain damages. These damages are called external corrosion of pipelines. The soil is complex three-phased

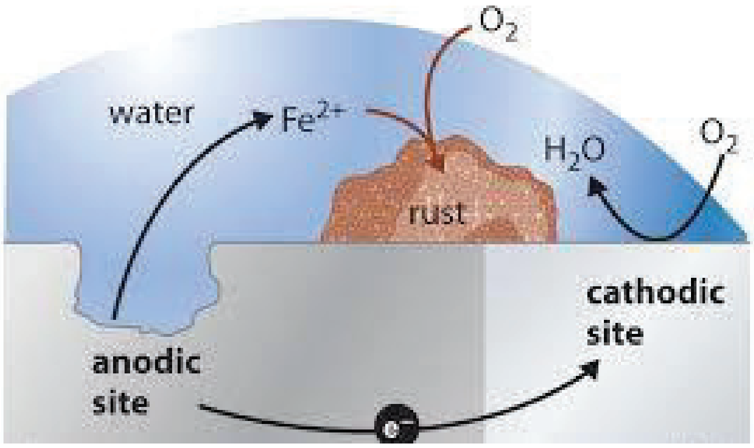

Figure 1.
Schematic of anodic site and cathodic site as they lead to corrosion [9].

system, which makes it a conductor to the metal pipelines. Plus, the oxygen concentration cell caused by the oxygen concentration difference accelerates the pipeline corrosion [13].

- Differential cell corrosion
- Galvanic corrosion

2.3 Control and prevention of corrosion in the oil and gas industry

Control and prevention of corrosion in the oil and gas industries has been on for a long time. Although many methods have been suggested to arrest corrosion, they can be classed broadly into four main categories; selection of appropriate materials, use of inhibitors, use of protective coatings and cathodic protection [13].

3. Corrosion inhibitors

An inhibitor is a substance that, when added in small concentrations to an environment, decreases the corrosion rate. In a sense, an inhibitor can be considered as a retarding catalyst. There are numerous inhibitor types and compositions and are generally classified into organic and inorganic inhibitors (**Figure 2**). Most inhibitors have been developed by empirical experimentation, and many inhibitors are proprietary in nature and thus their composition is not disclosed. The chemicals, their concentration, and the frequency of injection depend on the process medium and, normally, on the recommendations of the inhibitor manufacturer, since these chemicals, although generic in nature, are generally proprietary items [10, 13, 15]. The inhibitors used are normally chromates, phosphates, and silicates, added following the recommendations of the manufacturer. The removal of oxygen from a fluid medium improves the chances of corrosion resistance by materials in contact with the fluid. Controlling and stabilizing the pH value of the medium is another method of combating corrosion Inhibition is not completely understood because of these reasons, but it is possible to classify inhibitors according to their mechanism and composition. The corrosion rates of usefully resistant materials generally range between 1 and 200 mpy [10, 13, 15].

3.1 Inorganic corrosion inhibitors

Substances, such as arsenic and antimony ions, specially retard the hydrogen-evolution reaction. As a consequence, these substances are very effective in acid

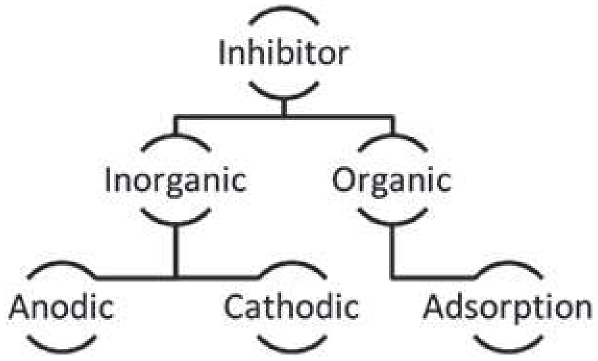

Figure 2.
Classification of inhibitors [14].

solutions but are ineffective in environments where other reduction processes such as oxygen reduction are the controlling cathodic reactions [15]. Scavengers are substances that act by removing corrosive reagents from solution. Oxidizers are substances as chromate, nitrate, and ferric salts also act as inhibitors in many systems. In general, they are primarily used to inhibit the corrosion of metals and alloys that demonstrate active-passive transitions, such as iron and its alloys and stainless steels [15]. Vapor-phase inhibitors are very similar to the organic adsorption-type inhibitors and possess a very high vapor pressure. Generally, the inorganic inhibitors have cathodic actions or anodic.

3.1.1 Anodic inhibitors

Anodic inhibitors (also called passivation inhibitors) act by a reducing anodic reaction, that is, blocks the anode reaction and supports the natural reaction of passivation metal surface, also, due to the forming a film adsorbed on the metal. In general, the inhibitors react with the corrosion product, initially formed, resulting in a cohesive and insoluble film on the metal surface [14, 16, 17]. The anodic inhibitors reacts with metallic ions Me^{n+} produced on the anode, forming generally, insoluble hydroxides which are deposited on the metal surface as insoluble film and impermeable to metallic ion, from the hydrolysis of inhibitors results in OH^- ions [16]. Some examples of anodic inorganic inhibitors are nitrates, molybdates, sodium chromates, phosphates, hydroxides and silicates [14, 15]. Potentiostatic polarization diagram showing electrochemical behavior of a metal in a solution with anodic inhibitor (a) versus without inhibitor (b) is illustrated in **Figure 3**.

3.1.2 Cathodic inhibitors

As the corrosion process begins, the cathodic corrosion inhibitors prevent the occurrence of the cathodic reaction of the metal. These inhibitors have metal ions able to produce a cathodic reaction due to alkalinity, thus producing insoluble compounds that precipitate selectively on cathodic sites. Deposit over the metal a compact and adherent film, restricting the diffusion of reducible species in these areas. Thereby, increasing the impedance of the surface and the diffusion restriction of the reducible species, in this case, the oxygen diffusion and electrons conductive in these areas. These inhibitors cause high cathodic inhibition [14, 16–18]. **Figure 4** shows an example of a polarization curve of the metal on the solution with a cathodic inhibitor. When the cathodic reaction is affected the corrosion, potential

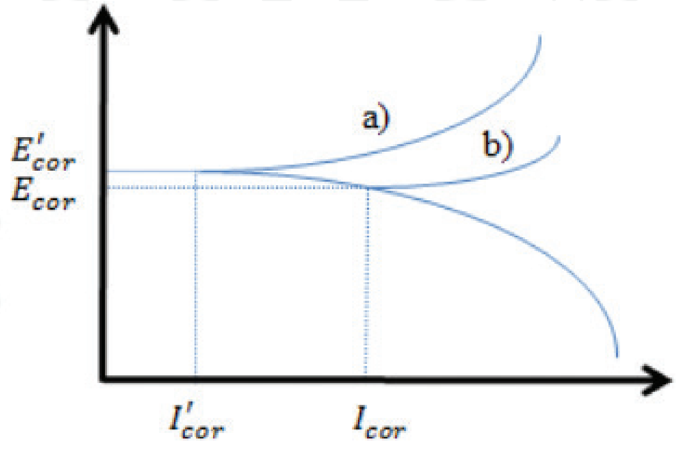

Figure 3.
Potentiostatic polarization diagram: electrochemical behavior of a metal in a solution with anodic inhibitor (a) versus without inhibitor (b) [14].

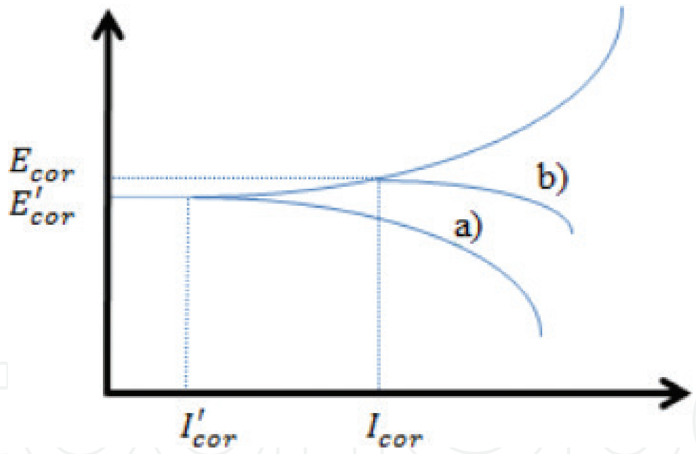

Figure 4.
Potentiostatic polarization diagram: electrochemical behavior of a metal in a cathodic inhibitor solution (a), as compared to the same solution without inhibitor (b) [14].

is shifted to more negative values [15]. When cathodic inhibitors minimize the release of hydrogen ions due to a phenomenon that can difficult the discharge of the hydrogen, called overvoltage [14].

3.2 Organic corrosion inhibitors

Environmental concerns require corrosion inhibitors to be nontoxic and environment friendly and acceptable. Green chemistry serves as a source of environmental friendly green corrosion inhibitors. Corrosion inhibitors are extensively used in corrosion protection of metals and equipment. Organic compounds with functional groups containing nitrogen, sulfur, and oxygen atoms are generally used as corrosion inhibitors. Most of these organic compounds are not only expensive but also harmful to the environment. Thus, efforts have been directed toward the development of cost effective and nontoxic corrosion inhibitors. Plant products and some other sources of organic compounds are rich sources of environmentally acceptable corrosion inhibitors. An example of such a system is the corrosion inhibition of carbon steel by caffeine in the presence and absence of zinc. Plant products are a source of environment-friendly green inhibitors such as phthalocyanines [2]. After the addition of the inhibitor, the corrosion potential remains the same, but the current decreases from I_{cor} to I'_{cor}. Is showed in **Figure 5** the mechanism of actuation of organic inhibitors, when it is adsorbed to the metal surface and forms a protector film on it.

The inhibitor efficiency could be measured by the follow equation:

$$Ef = \frac{R_i - R_o}{R_o} x\,100 \qquad (1)$$

where E_f is inhibitor efficiency (percentage), R_i is corrosion rate of metal with inhibitor and R_o is corrosion rate of metal without inhibitor [14].

3.3 Corrosion inhibitor mechanism

Corrosion inhibition mechanisms operating in an acid medium differs widely from one operating in a near-neutral medium. Corrosion inhibition in acid solutions can be achieved by halides, carbon monoxide, and organic compounds containing functional group heteroatoms such as nitrogen, phosphorus, arsenic, oxygen, sulfur, and selenium, organic compounds with multiple bonds, proteins, polysaccharides, glue, bitumen, and natural plant products such as chlorophyll and anthocyanins [19]. The initial step in the corrosion inhibition of metals in acid solutions consists of adsorption of the inhibitor on the oxide-free metal surface followed by retardation of the cathodic and/or the anodic electrochemical corrosion reactions [19]. Corrosion inhibitors work by forming a protective film on the metal preventing corrosive elements contacting the metal surfaces, as illustrated in **Figure 6**.

The action mechanisms of corrosion inhibitors are;

- By adsorption, forming a film that is adsorbed onto the metal surface,
- By inducing the formation of corrosion products such as iron sulfide, which is a passivizing species,
- By changing media characteristics, producing precipitates that can be protective and eliminating or inactivating an aggressive constituent.

It is well known that organic molecules inhibit corrosion by adsorption, forming a barrier between the metal (pipeline) and the environment. Thus, the polar group of the molecule is directly attached to metal and the non-polar end is oriented in a vertical direction to the metal surface, which repels corrosive species as illustrated in **Figure 6**, furthermore establishing a barrier against chemical and electrochemical attack by fluids on the metallic surface [20, 21].

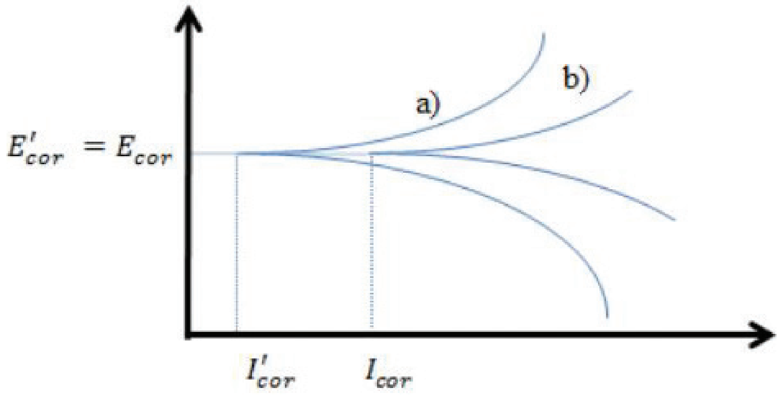

Figure 5.
Theoretical potentiostatic polarization diagram: electrochemical behavior of a metal in a solution containing a cathodic and anodic inhibitor (a) compared to the same solution without the inhibitor (b) [14].

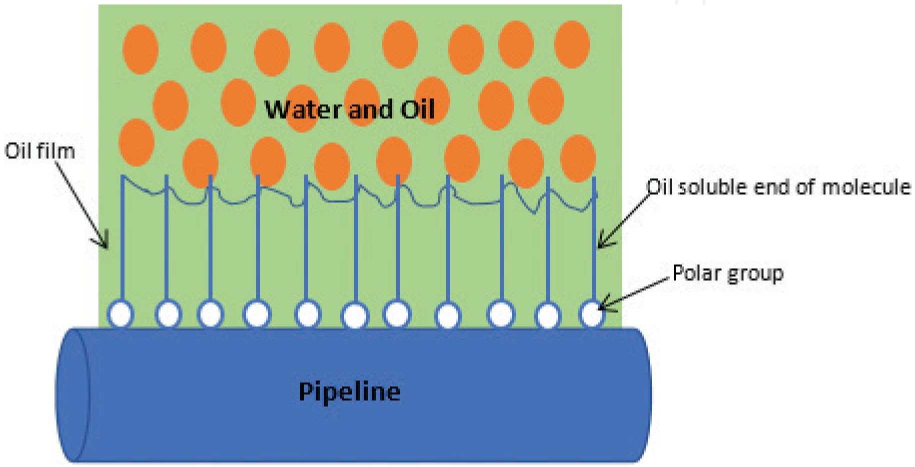

Figure 6.
Schematic of modified inhibitor film prevents water contacting a pipeline surface.

An inhibitor may be effective in one system, while in another it is not, therefore, it is convenient to consider the following factors: chemical structure of the inhibitor component, chemical composition of the corrosive medium, nature of the metal surface (pipeline), operating conditions (temperature, pressure and pH) thermal stability of the inhibitor—corrosion inhibitors have temperature limits above which lose their effectiveness because they suffer degradation of the containing components, solubility of the inhibitor in the system—the solubility of the inhibitor in the system is required to achieve optimum results in the metal surface protection; this depends on the length of the hydrocarbon chain, the addition of surfactants to enhance the dispersibility or solubility of inhibitors, and modification of the molecular structure of the inhibitor by ethoxylation to increase the polarity, and thus reach its solubility in the aqueous medium [21].

The main features of an inhibitor are:

- Ability to protect the metal surface.
- High activity to be used in small quantities (ppm).
- Low cost compounds.
- Inert characteristics to avoid altering a process.
- Easy handling and storage.
- Preferably with low toxicity.
- Non-contaminant.
- It should act as an emulsifier.
- It should act as a foaming agent [21].

4. Paints for corrosion protection

Paints are made up of a mixture of different components, although paints designed for different purposes will have different formulations, they all have some key features in common. Paints contain a pigment to give color, including white; a film former that binds the pigment particles together and binds them to the surface to be painted; a liquid that makes it easier to apply the paint and additives to make the basic paint better to store and to use. There are two main types of paint, which are gloss and emulsion [22]. **Table 1** shows a typical gloss paint formulation.

4.1 Alkyd resin binder

The alkyd resins produced this way are referred to as oil-modified alkyd resins and contribute about 70% to the conventional binders used in surface coating [23]. They determine the performance quality of surface coatings such as the rate of drying, gloss, durability of the dry film and resistance of the dry film to abrasion and chemicals. However, classification of alkyd resins is based on the oil length and oil type [24]. The vegetable oils used in oil-modified alkyd resins are usually extracted either by mechanical press or solvent extraction [25]. The natural oil in the oil-modified alkyds reacts with atmospheric oxygen leading to the formation of

Component	Mass (%)
Alkyd resin binder	30
Pigment	25
Solvent	40
Additives	5

Table 1.
A typical gloss paint formulation [22].

network of polymers cross-linked through the C=C bond. The oxidative drying of the oil brings about the formation of film that shows improved properties with drying time, hardness or water resistance [26]. The oils used in surface coatings contain linolenic and conjugated acid groups, such oils include linseed, perilla and tung oils and possess pronounced drying abilities [27]. There has been tremendous increase in the demand for alkyd resin production for use in the Nigerian surface coating industry due to the rapid growth of the economy [27].

4.2 Red oxide pigment

The use of iron oxides as natural pigments has been practiced since earliest times. The iron oxides such as magnetite, hematite, maghemite and goethite are commonly used as pigments for black, red, brown and yellow colors respectively. Predominantly natural red iron oxides are used in primers for steel constructions and cars reducing corrosion problems. Iron oxide are strong absorbers of ultraviolet radiation and mostly used in automotive paints, wood finishes, construction paints, industrial coatings, plastic, nylon, rubber and print ink [28].

4.3 Solvent

Solvents are not the only means of removing low molecular weight compounds. Heat can help evaporate saturated fatty acids, such as palmitic and stearic acids, and an improperly stored or displayed painting can become embrittled by the loss of these plasticizers. The long-term behavior of oil paints also seems to indicate that a small amount of evaporation of fatty acids occurs over time. Improper temperature on a hot table may do so as well since the volatility of the fatty acids becomes significant above 70–80°C [29].

The mechanical properties of a paint film depend upon its basic structure and the presence of small organic molecules that may act as plasticizers. The original structure of a paint film contains the ester bonds of the oil and the bonds produced by the cross-linking of the unsaturated fatty acids through autoxidation. The loss of any of these bonds results in weakening the film strength. Any loss of the ester bonds must have a significant effect on the structure of the oil paint. After 6 years, the paints made with varying degrees of hydrolyzed oil appear as coherent films, but some disintegrate when solvents, such as acetone or toluene, are applied because these solvents can remove the low molecular weight compounds that contribute to the stability of the paints [29].

4.4 Additives

Additives are small amounts of substances that modify the paint properties, additives might be driers anti-skin agents, anti-corrosive agents, antifreeze, dispersing aids, wetting agents, thickeners, biocides, low temperature drying aids, anti-foam agent, and coalescing solvent. Driers accelerate the paints drying (hardening) by catalyzing the oxidation of the binder, while plasticisers increase the paints flexibility. Fungicides, biocides and insecticides prevent growth and attack of fungi, bacteria and insects and flow control agents improve flow properties. Defoamers prevent formation of air bubbles entrapped in the coatings, emulsifiers are wetting agents increasing the colloidal stability of the paints in liquid state, while UV stabilizers provide stability of the paints under ultra-violet light, and anti-skinning agents prevent formation of a skin in the can. Adhesion promoters improve the adhesion of the coating to the substrate, and texturizers impart textures to the coatings [29].

4.5 Nanoparticles

Nanoparticles are important scientific tools that have been and are being explored in various biotechnological, pharmacological and pure technological uses. They are a link between bulk materials and atomic or molecular structures. While bulk materials have constant physical properties regardless of its size, among nanoparticles the size often dictates the physical and chemical properties. Thus, the properties of materials change as their size approaches the nanoscale and as the percentage of atoms at the surface of a material becomes significant. For bulk materials, those larger than 1 μm (or micron), the percentage of atoms at the surface is insignificant in relation to the number of atoms in the bulk of the material. Nanoparticles are unique because of their large surface area and this dominates the contributions made by the small bulk of the material [30, 31].

In typical nanomaterials, the majority of the atoms located on the surface of the particles, whereas they are located in the bulk of conventional materials. Thus, the intrinsic properties if nanomaterials are different from conventional materials since the majority of atoms are in a different environment. Nanomaterials represent almost the ultimate in increasing surface area and they are chemically very active because the number of surface molecules or atoms is very large compared with the molecules or atoms in the bulk of the materials. Substances with high surface areas have enhanced physical, chemical, mechanical, optical and magnetic properties and this can be exploited for a variety of structural and non-structural application. Nanoparticles/fillers find application in wear-resistant, erosion-resistant and corrosion resistant [31]. Coatings with nanostructure bring about a reduction in surface contact tension, minimization of moisture penetration, and reduction in surface roughness to 1 nm for better dirt repellence [31].

4.6 Synthesis of nanoparticles

Nanoparticles of various types has been synthesized; gold, silver, magnetite, zinc oxide, silicon oxide, and others [32–35], which can be synthesized using methods such as the breakdown (top-down) method and the build-up (bottom-up) method [33].

5. Plant extracts

Plants naturally synthesize chemical compounds in defense against fungi, insects and herbivorous mammals. Some of these compounds or phytochemicals such as alkaloids, terpenoids, flavonoids, polyphenols and glycosides prove beneficial to humans in unique manner for the treatment of several diseases. These compounds are identical in structure and function to conventional drugs. Extracts from parts of plants such as roots, stems, and leaves also contain such extraordinary phytochemicals that are used as pesticides, antimicrobials, drugs and herbal medicines [4, 36–38].

5.1 Plant extracts as green inhibitors

Plant extracts are excessively used as corrosion inhibitors. Plant extracts contain a variety of organic compounds such as alkaloids, flavonoids, tannins, cellulose and polycyclic compounds. The compounds with hetero atoms-N, O, S, P coordinate with (corroding) metal atom or ion consequently forming a protective layer on the metal surface, which prevents corrosion. These serve as cheaper, readily available, renewable and environmentally benign alternatives to costly and hazardous corrosion inhibitors (e.g., chromates). Plant extracts serve as anticorrosion agents to various metals such as mild steel, copper, zinc, tin, nickel, aluminum and its alloys [37, 38].

There are exhaustive numbers of plant extracts that have shown proven anticorrosion activity as corrosion inhibitors. Examples are *Swertia angustifolia*, *Acacia concinna*, *Emblica officinalis*, *Terminalia chebula*, *Terminalia belivia*, *Sapindus trifoliatus*, *Pongamia glabra*, Eucalyptus leaves, *Annona squamosa*, *Eugenia jambolana*, *Azadirachta indica*, *Acacia arabica*, *Vernonia amygdalina*, *Carica papaya*, *Rosmarinus officinalis*, *Hibiscus sabdariffa*, Opuntia extracted, *Mentha pulegium*, *Ocimum viridis*, *Datura metel*, *Ricinus communis*, *Chelidonium majus*, Papaia, *Poinciana pulcherrima*, *Cassia occidentalis* and *Datura stramonium* seeds, Papaia, *Calotropis procera* B, *Azydracta indica*, *Justicia gendarussa*, *Artemisia pallens*, *Auforpio turkiale* sap, Black pepper extract, henna extract and several others [4, 36–38].

5.2 Cassava plant

Cassava can be grown on a wide range and can yield satisfactorily even in acidic soils where most other crops fails [39], the crop has continually played very vital roles, which include income for farmers, low cost food source for both the rural and urban dwellers as well as household food security. In Nigeria, Cassava is generally believed to be cultivated by small scaled farmers with low resources. It also plays a major role in the effort to alleviate the food crisis in Africa [39]. Cassava with botanical name *Manihot esculenta*, is a woody shrub of the spurge family, Euphorbiaceae, native to South America. It is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates [40]. World production of cassava root was estimated to be 245 million tonnes in 2012 [41]. Africa produces about 137 million tonnes, which is the largest contribution to the world production; 75 million tonnes is produced from Asia; and 33 million tonnes in Latin America and the Caribbean, specifically Jamaica. Nigeria is the world’s largest producer of cassava, producing about 37.5 million tonnes annually [41]. A mature cassava root (hereafter referred to as ‘root’) may range in length from 15 to 100 cm and weigh 0.5–2.5 kg. Circular in cross-section, it is usually fattest at the proximal end and tapers slightly toward the distal portion. It is connected to the stem by a short woody neck and ends in a tail similar to a regular fibrous root.

5.2.1 Cassava bark (CB)

Cassava bark also known as cassava peels are always dumped in abundant as waste. Although, it has been reported that both leaf and bark contains cyanogenic glucosides, linamarin, lotaustralin, starch, amino acid, carbohydrate, proteins and tannin [41]. Cassava bark (CB) consist of two layers namely; the outer skin and inner skin [42], both layers combine together serves as agro-waste and since annual production is high and it has been reported that the bark consist of 5–10% of the cassava root [42–44], the amount of agro-waste that can be generated from cassava bark is significant. CB is used for animal feed [42], biogas [43].

5.2.2 Cassava leaf (CL)

Cassava leaves are sometimes considered as agro-waste, though it has other applications such as animal feed [42, 45], medicinal application (Aro, 2008) and pack-cyaniding of mild steel [45]. Cassava leaves are also known for their high HCN content, low energy, bulkiness and their high tannin content [42, 45]. Cassava leaves are nutritionally valuable products and cassava plant could yield 7–15 tonnes of leaves per hectare, which accounts for an additional 1 tonne of valuable protein and 2.5 tonnes of carbohydrate per hectare [42]. Up to 6% of cassava leaves can be obtained from the total production of cassava [42].

5.2.3 Cassava stem (CS)

Cassava stem is the largest waste generated from cassava plantation after harvest, up to 400 bundles can be obtained per hectare (Information and Communication Support for Agricultural Growth in Nigeria, 2015). From the estimated amount of cassava stem waste generated it shows that enough can be obtained for processing into useful application. Cassava stem can be fed to pigs, poultry, dairy cattle [45] and biochar production [46].

5.3 Synthesis of cassava plant extract nanoparticles (CPENPs)

CPENPs which comprises of cassava bark nanoparticles (CBNPs) [47], cassava leaf nanoparticles (CLNPs) [48] and cassava stem nanoparticles (CSNPs) [48] were obtained by first soaking for 24 h, after which ball milling for 60 h was carried out, to achieve a particles size below 100 nm which were estimated by SEM/Gwyddion software, XRD and TEM [47, 48]. Trace elements such as O, Si, Ca, K, Fe and S, were revealed using EDX, which are hetero-atoms and can be added to coatings to help in inhibiting corrosion on metal surfaces [47, 48]. Elements like Si and Ca would improve the strength of coatings as well as reduce corrosion rate of coated metals [47, 48]. XRD revealed compounds such as SiO_2, $CaCO_3$, $Ca_2(SO_4)_2H_2O$ and $CaC_2O_4(H_2O)$, these compounds would help in improving the mechanical properties of alloys or composites and coatings. SiO_2 if added to coatings will improve the coating hardness, while the presence of $CaCO_3$ in coatings will form a precipitate that will serve as a protective film on the surface of the metal, thereby protecting the metal from corrosion. FTIR result revealed the nature of bond that exist in the CLNPs and GC–MS result showed various organic compounds that were presence in the CLNPs [48]. These organic compounds can be classified as fats, waxes, alkaloids, proteins, phenolics, simple sugars, pectins, mucilages, gums, resins, terpenes, starches, glycosides, saponins and essential oils. All of which helps improve the properties of metallic coatings [47, 48]. This chapter discuss the synthesis and characterization of CPENPs which can be used as additives to coatings for corrosion protection, especially coatings for oil and gas applications due to the properties as discussed by Kolawole et al. [46–48]. Therefore, CPENPs should not be left to waste as they are useful for additives in coatings. These will add value to the CPENPs that is usually dumped in the environment and also reduces environmental pollution.

6. Conclusions

Utilization of cassava plant extract (bark, leaf and stem) nanoparticles as green corrosion inhibitors incorporated into paint or coatings as an additive. The cassava plant part waste utilized will reduce the amount of waste contributing to environmental nuisance. The cassava plant solid extract (bark, leaf and stem) will serve as wealth creation to the farmers and value addition to the cassava waste. The developed corrosion resistant paint will enhance corrosion resistant of API 5 L X65 steel pipeline used in the oil and gas industries. Since the world production of cassava is about 268 million tonnes annually, the cassava waste generated will be significantly high, therefore the developed corrosion resistant paint will be cheaper and efficient because of the presence of heteroatoms and organic compounds which help in inhibiting corrosion.

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Conflict of interest

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