Corrosion of tin can and its inhibition: A review

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Abstract

Tin is a chemical element which is represented by the symbol Sn. Tin is most commonly used in the form of tin cans. Food cans mainly store food stuff and used by packaging industry. The corrosion is a major problem in tin cans and a matter of great concern for the corrosion engineers as well as researchers. This article deals with corrosion behaviour of tin cans in different media and its inhibition. Researches which have been done on dissolution of tin in different types of canned products containing hydrochloric acid, tartaric acid, citric acid, maleic acid and formic acid have been described here since acids have a great tendency of dissolving the metal to which they come into contact. It has been found that artificial fruit juices and preservatives augment the rate of corrosion as compared to natural juices and acids. The comparative study of the rate of corrosion in tin cans under different conditions along with the techniques to determine the rate of corrosion has been studied The literature review on a wide range of corrosion inhibitors used to inhibit corrosion has been systematically carried out. The main purpose of this review is to showcase the various cases of corrosion mechanism and inhibition methodologies to combat corrosion of tinplate.

Keywords: *tin can, tin plate corrosion, corrosion mechanism, corrosion inhibition.*

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1. Introduction

In general Tin is a non ferrous metal which finds wide use in making beverage cans, food cans, artistic cans and not only that but its application extends to manufacturing of electrical machinery parts *etc.* [1]. Tin has fine metallic lusture, quite resistance to corrosion and finds ease in several mechanical processes like soldering and welding. Now since tin cans are mostly used for preserving food and beverages, it has a tendency to get dissolved and mixed in the product which is to be preserved thereby causing many serious problems to human health like gastrointestinal disorders and other issues like toxicity to the consumers due to dissolution of tin metal in pickles and other acidic food items [2]. Tin can is widely used in packaging industry. The consumption of one-third of tin is used for the manufacturing of tin can. The manufacturing of tin with a varied application is consumed more than 2.5 million every year. It is reported that 25% of manufacturing is only for beverage tin cans. Industrial application of tin is limited by its low strength. Tin cans have a wide range of utility for packing foods, beverages, aerosol products which find it quite useful for preservation of food products and give long shell life [3].

1.1 Historical background

Tin was first used in Mesopotamia in 3500 BC currently in Iraq. Peter Durand an Englishman in 1813 patented tin can. The usage of tin for various purposes has been since ages. In ancient times, about 40% of tin was blended with copper to make bronze alloy. In Eastern Mediterranean region the supply of tin was cut off to various civilizations. It was realized by Sumerians in 2050 BC that if different ores could be blended together, especially with tin a different form of copper was formed which was easy to cast and comparatively harder. The antique of values of elements such as gold, silver, tin, copper, lead and mercury have been recognized.

1.2 Economic importance

Tin finds various applications in the automobile engine manufacturing industry. It is also applied as an internal coat/layer in food, beverage cans *etc*. The major countries which were the producer of tin were Malaysia, China, Bolivia and Indonesia. Tin can exports faced hikes by about 150% in agriculture [4]. As per analysis made by, tin will find wide range of applications in electric vehicles (EVs), robotics as well as renewable energy. The International Tin Association (ITA) forecasted that tin markets will sink by about 4 percent in 2019 as compared to what was in [5]. As a whole, tin metal will help to maintain the economic status of a country. Several countries including Nigeria have advanced their custom rules to increase revenue generation [6].

1.3. Mechanism of corrosion in tin cans

Tin plate basically consists of tin coated in the inner side of the steel plate (which is in contact with the canned product). Due to scratches, we find areas where Tin Iron alloy (Fe-Sn alloy) is exposed and that becomes the prime area for corrosion to occur. Metals when exposed to air form an oxide film due to the reaction between steel, moisture and atmospheric oxygen which causes rusting of the metals leading to its destruction. The process of rust formation is quite complex which can be illustrated by a simple reaction.

$$4Fe + H_2O + 3O_2 = 2Fe_2O_3 \cdot H_2O \quad (1)$$

The corrosion rate depends on the food item which is preserved in it. The base metal of tin can is steel which acts as a cathode and tin which is the inner most portions subjected to food as in case of tin can acts as an anode. The rate of corrosion highly depends upon the type of food product, composition, grade of tin plate. In presence of sulfur dioxide, sulfite and oxygen the rate of corrosion accelerates and are more harmful to the can products. Numerous studies have revealed that dissolution of tin into the canned product involves the evolution of hydrogen [7]. The products which contain acids cause formation of complexes which ultimately result in destruction of tin metals [8–13].

1.4 Factors affecting corrosion

Several factors affect the rate of corrosion of tin plate [14–17] which include:

1. Composition of material (grain size, surface morphology, base steel *etc*.)
2. Type and nature of coating *i.e.* epoxy, polyester, acrylic resin *etc.*
3. Canned product (food, beverages, and storage conditions)
4. Temperature and duration of storage
5. Can processing techniques which include cleaning, canning, exhausting, sealing and sterilizing.

If the content of oxygen is disturbed the growth of bacteria will increase and shelf life of canned food will be reduced. Under the adequate processing parameters, abnormal content of oxygen and spoilage bacteria will flourish in the can containers, and thus the shelf life of canned food will be shortened [18].

Tin as a highly workable and also was once as valuable metal like silver for making jewellery, coins, and special dishware. Nowadays, it is used in manufacturing of sheets and various construction materials, for soldering or joining metal parts, for storage containers, and in alloys like bronze and Babbitt metal.

Tin is an element of Group IV with four valence electrons, so it yields both divalent and tetravalent oxides and ions but preference is for the tetravalent species [19]

$$2SnO_2 \rightarrow 2Sn + 2O_2 \quad \Delta G^0 = -586513 + 215.6T \text{ (J/mol)} \qquad (2)$$

$$Sn^{4+} + 2e^- \rightarrow Sn^{2+} \quad \Delta E^0 = +0.15 \text{ V (SHE)} \qquad (3)$$

$$Sn^{2+} + 2e^- \rightarrow Sn \quad \Delta E^0 = -0.136 \text{ V (SHE)} \qquad (4)$$

Tin is quite stable, it undergoes passivation due to the formation of SnO_2. Tin dioxide SnO_2 has a rutile structure *i.e.* close packed structure and it is electropositive in nature.

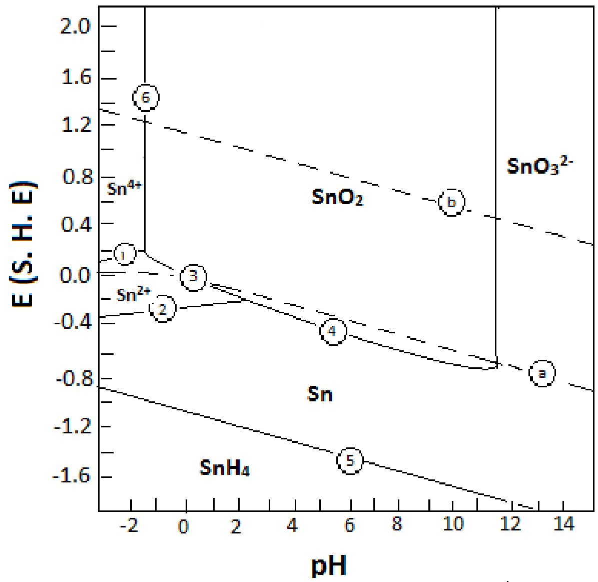

Figure 1. Pourbaix diagram of Sn–H_2O at 25°C (SnH_4 is volatile in nature).

The Pourbaix diagram of tin-water system shows regions of "Immunity" *i.e.* the resistance of a particular metal towards corrosion as it not attacked by the environment; likewise "Corrosion" the pattern of chemical attack and "Passivity" the formation of oxide layer which further retards corrosion. This plot basically shows the immunity of a particular tin metal in a specified environment and its tendency to corrode. In this context the plot shows tin behaviour at different pH. The Pourbaix diagram, for tin-water system at 25°C clearly predicts corrosion resistance in mild aqueous media, although the domain of stability of tin and water do not overlap in the pH range 0–14, corrosion current are limited by the passive surface, which resist the access of dissolved oxygen [19]:

$$O_2 + 2H^+ + 2e^- = H_2O \quad (5)$$

And higher hydrogen over potential prevents hydrogen evolution;

$$2H^+ + 2e^- = H_2 \quad (6)$$

The bivalent Sn(II) shows a second oxide phase. The Sn(II) oxidation is quite sensitive, therefore the passivation of tin is mostly regarded due to the rutile structure of the dioxide [20].

2. Internal corrosion of tin cans

The use of tin coating on the inner surface of cans is to protect the steel which is a cathode. The tin on the inner surface acts as a sacrificial anode. Small pores and fractures on the tin surface leads to corrosion as oxygen penetrate via these pores and allow rusting of steel. Y. Che [21] *et al.* conducted potentiostatic measurements and found that corrosion of tinplate undergoes a three stage anodic process. Under anaerobic conditions, the tin has to be anodic to steel. The stages (Figure 2) involves nucleation followed by a growth of a passive oxide layer *i.e.* the first stage, second stage involved pit nucleation and the third stage showed re-passivation. Corrosion generally occurs in three stages [17]:

1. In the first stage, the dissolution of tin occurs through nucleation which is followed by growth of passive oxide layer.
2. During the second stage, the pores and scratches increase in their sizes due to dissolution of tin thereby exposing the cathodic steel making it more prone to corrosion. This stage consumes a lot of time as it is slow and gradual.
3. The final stage represents the end of shelf life of tin can as large area of tin is being dissolved in the canned product [22–24].

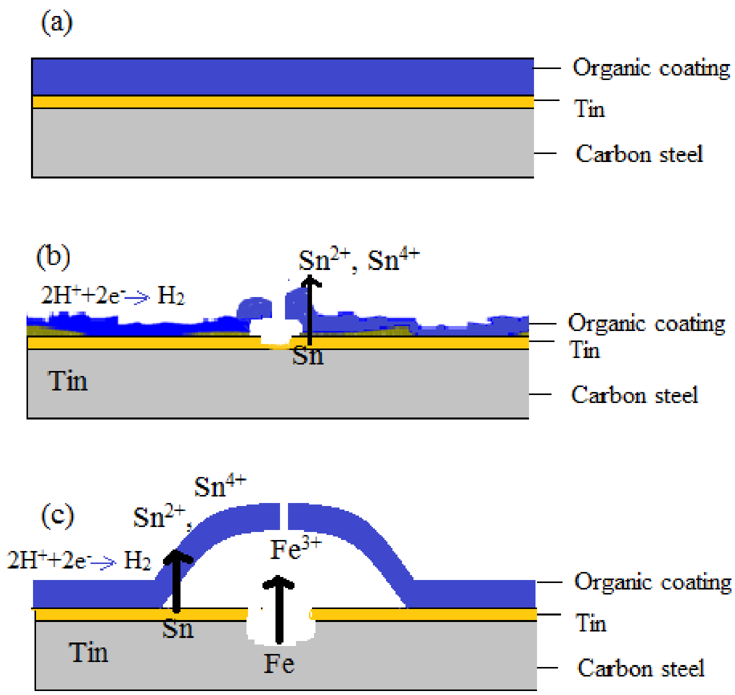

Figure 2. Tin plate corrosion.

2.1 Types of corrosion

There are basically three types of corrosion encountered by tin cans which is categorized as:

a) ***Filiform corrosion***: It occurs under the thin coatings of tin and distributes throughout the tin film like little threadlike fragments. They usually bulge or crack the coating.

b) ***Pitting corrosion***: Occurs in a specific surface area. It basically occurs due to sticking of the dirt particles on the surface. Crevice corrosion, water line attacks and concentration cell corrosion also takes place in tin cans.

*c)**Erosion corrosion***: It is a long term phenomena *i.e.* it takes place over a long period of time. Erosion commences with a tiny air bubble and then slowly continues [16].

2.2 Dissolution of tin in different types of canned products

The canned products which are acidic in nature allow the tin can material to get dissolved in them thereby causing toxicity as well as gastrointestinal disorders to the consumers. However the safe limits for tin dissolution in the canned product are of main concern to the corrosion engineers. The tin can corrosion decides the shelf life of the tin can [25].

When fruit juices are stored in tin cans corrosion occurs as formation of complexes takes place like formation of oxalic acid, citric acid, maleic acid *etc*. Food colorants, preservatives artificial flavors also affect the rate of corrosion of tin. The reason behind this is that two or more sulfuric acid groups that form soluble compounds are present in beverages, fruit juices *etc*. Hydroxyl groups present also increase the corrosion rate of tin [26].

3. Behavior of tin in different types of media

Various researches have been conducted round the globe, which reveals the behaviour of tin in different media, *i.e.* acids, salts and natural fruit juices *etc*. The various analytical techniques and surface studies have been employed in order to assess the corrosion rate under different concentration.

3.1 Acids

3.1.1 Tartaric acid

Rabab M. El-Sherif *et al.* [27] studied the electrochemical behaviour of tin metal in tartaric acid solution at different concentrations using amino acids like alanine, glycine, glutamic acid and histidine which acted as environmental friendly corrosion inhibitors. Electrochemical techniques adopted for analysis were potentiodynamic polarization and electrochemical impedance spectroscopy (EIS). The analysis was carried out by using Scanning Electron Microscope (SEM). The study reflected that there was an augmentation in tin can dissolution with an increase in Tartaric acid concentration, as the anodic behaviour of tin was responsible for its active and passive transition as the E/I curves were revealing.

3.1.2 Citric acid

E.E. Foad *et al.* [28] analysed the electrochemical behaviour of tin at various concentrations of citric acid solutions ranging from 0.1 to 1.0 M with the implementation of cyclic voltametric technique under different conditions. The potentiodynamic polarization curves were plotted and it showed anodic behaviour of tin exhibiting active/passive transition. The anodic dissolution of tin increased substantially due to the addition of Cl, Br or I ions. The potentiodynamic polarization curve in the presence of three polyethylene glycols indicated that these three polymers used showed good inhibition efficiency. G. Bereket *et al*. [29] also analysed the behaviour of tin in citric acid at pH and pH 6 in concentrations of 10^{-1} and 10^{-4} M. I_{corr} values substantially decreased from 10^{-1} and 10^{-4} M concentrations. YChe *et al.* found that in case of an aerated citric acid solution, the shape of EIS spectra displayed a characteristic with two time constants after three days [21].

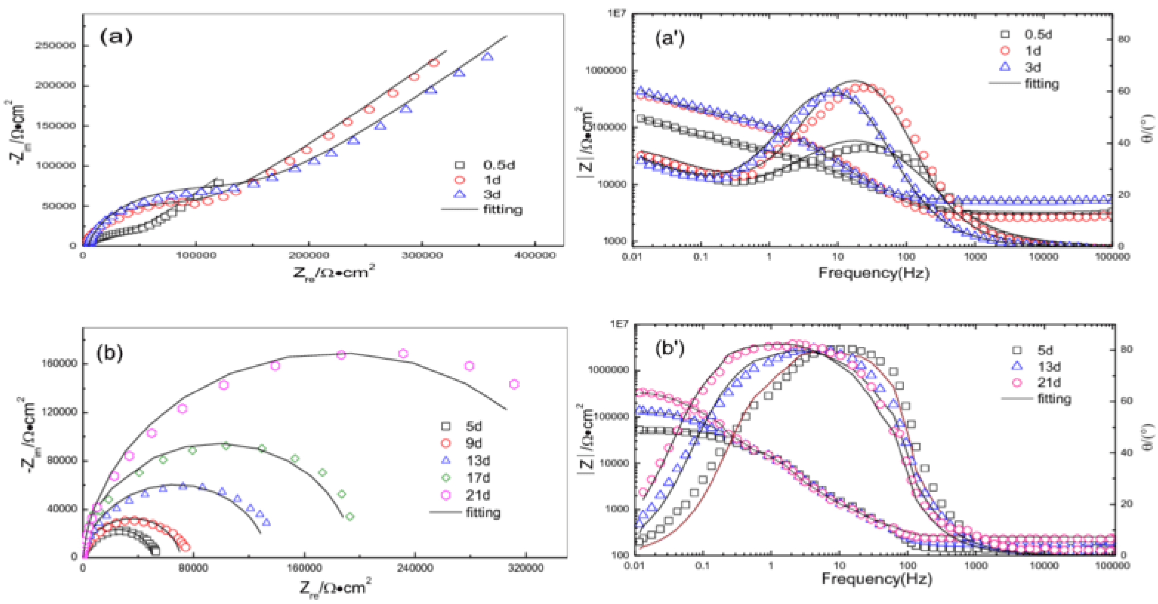

Figure 3. Corrosion mechanism differences of tinplate in aerated and deaerated citric acid solution.

3.1.3 Maleic Acid

B.O. Adewuyi *et al.* [30] analysed the corrosion of tin in aqueous medium which contained food colourants of various types (Sunset yellow, Carmosine, Tartazine and Poncreau 4R). Various types of sweeteners were also employed like Glycerol, Saccharin, Sucrose as well as glucose. They found that the corrosivity of acid containing artificial colours faces augmentation by addition of colourants and increase in acid concentration as well. But if the colourant concentration is kept constant and acid concentration is gradually increased, the order of corrosion for different colourants changes. as it used to be for increasing acid and colour concentrations. Sweeteners were found to act as inhibitors to corrosion [23–25].

3.1.4 Acetic acid

The corrosion rate of tin can in the presence of acetic acid (CH_3COOH) was studied, where the concentration ranges from 2 M–10.3 M by polarization technique [31, 32]. The studies revealed a linear relationship between corrosion potential (E_{corr}) and corrosion current (I_{corr}) *vs* acetic acid at low pH. H.H. Hassan *et al.* [32] studied the corrosion behaviour of tin plate in acetate buffer by three different techniques. The pit formation starts when the electrode potential shifts to more anodic region and solution becomes more concentrated. Meanwhile the nucleation rate increases and growth rate decreases.

3.1.5 Formic acid

S. Koyama *et al.* [33] analysed the effect of formic acid surface formation on the bond strength of Solid state bonded interfaced Tin which was analysed by SEM. Interfacial microstructures and fractures were observed. Solid state bonding process was being carried out in a vacuum chamber at bonding temperatures of 403–473 K at 7 MPa pressure with 1800 s bonding time. The analysis showed an increase in bond strength with the increase in bonding temperature. As surface modification took place, the bonded joints were found at low temperatures (40 K less than the typical bonding temperature) which resulted in the destruction of oxide film and augmentation in tensile strength**.**

3.1.6 Fruit juices

With the help of a weight loss technique, morphology and structures of corrosion products were deeply analysed with the aid of scanning electron microscope (SEM). When tin plate specimens of different weights were immersed in different kinds of synthetic fruit juices with preservatives, natural fruit juices and water for a period of 20 days. The weight loss was observed and noted at six day intervals. The studies revealed that artificial fruit juices with preservatives were more corrosive as compared to natural fruit juices and water due to the reason that it had high acidity [3, 26].

3.1.7 Hydrochloric acid

The dissolution of tin in HCl is slow in the absence of oxygen due to hydrogen displacement. When the sample is immersed into air-saturated HCl, tin dissolution takes place due to evolution of hydrogen. As the concentration of tin in the solution increases, corrosion displays auto-catalytic behaviour with corrosion rate proportional to the square of stannic concentration [34, 35].

3.1.8 Sulfuric acid

The study done through rotating-disk voltammeter showed anodic dissolution and partial passivation of tin in 4.5–8 M sulphuric acid. The study also revealed a Tafel slope of

$1/(30\pm3)\ mV^{-1}$ in the active dissolution. This behaviour was independent of acid concentration. A reaction mechanism explained this slope. The behavior of tin was in its bivalent form and it gets dissolved in both active as well as passive potential region. The surface studies like SEM, XRD, XPS and SIMS depicted that the film was composed of tin oxide [36].

3.2 Alkaline or neutral media

Most common of all salts *i.e.* common salt (NaCl) also shows inhibitory effects when mixed with nitrates and nitrites. At high temperatures, NaCl mixed with nitrates and nitrites show corroding properties. K. Galic *et al.* [14] performed an analysis by Auger electron spectroscopy and X-ray photo spectroscopy and got the polarization curves for tin electrode in NaCl environment. An anodic polarization of 400 mV made some identical changes. A.J. Bard *et al.* [15] found that an anti corrosion film was formed when NaCl was replaced with $SnCl_2$ .The tinplate behaviour highly depends on the nature of the electrolyte. The coated tinplate evolution is different, as well. The impedance decreases with immersion time in both types of electrolytes and no passivation is observed.

The studies revealed the possibility of attack on tin by solutions of high pH values (above 10.5). The position of this limit is influenced by the following factors;

a) Temperature
b) Composition of the solution, and
c) Condition of metal surface.

Corrosion will occur if the surface oxide is significantly soluble especially at pH = 12. As corrosion starts, the rate of corrosion is governed by the oxygen supply as well as temperature and is not greatly affected by the character of the alkali. The removal of oxygen from alkaline solutions can be done by adding sodium sulfite (oxygen scavanger), can very well prevent corrosion until unless tin is in contact with another metal, like steel, from which hydrogen evolution takes place. If some oxidizing agents is being added, they augment the rate of corrosion but too much amount is added, then it creates passivity forming a layer of chromium oxide [37, 38].

3.3 Coffee

Wang Ke *et al.* [39] studied the behaviour of tin cans containing coffee. It was investigated by the use of novel electrochemical impedance and electrochemical noise sensor. The study revealed that there was an increase in iron and tin with the storage time. The corrosion mechanism of corrosion in tinplates with coffee was discussed by the morphology of corroded surface done by optical microscopy and scanning probe microscopy. The results also revealed, that with the prolongation time the the coating resistance, charge transfer resistance and noise resistance decreases.

With the extension of the storage time, the EIS characteristics showed significant changes, varying from a feature of one capacitive loop to 2 capacitive loops. The graphs clearly reveal that the general shape of the impedance only includes impedance response of a degradation process of the organic coatings.

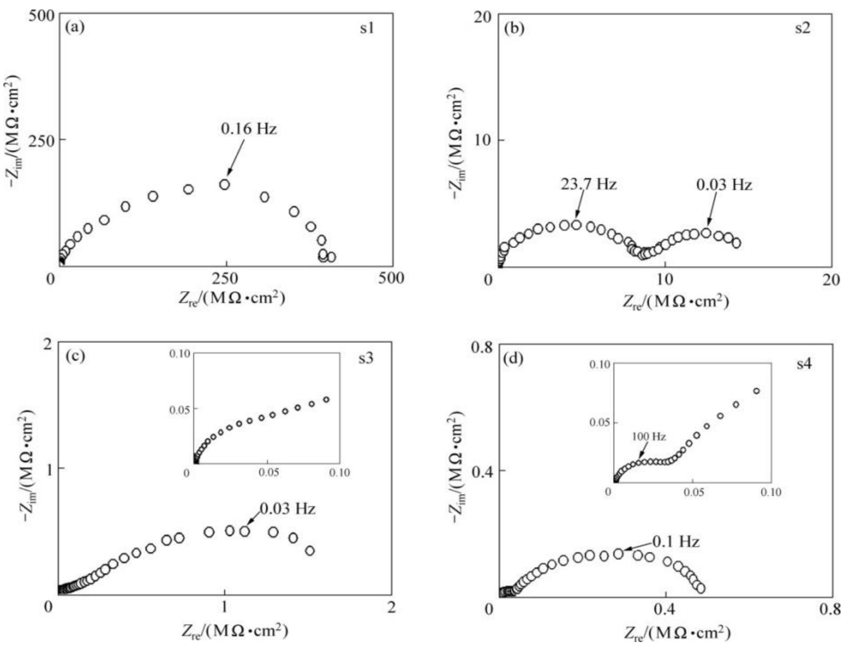

Figure 4. EIS plots of beverage cans with different storage time: (a) 1 month; (b) 3 months; (c), (d) 12 months.

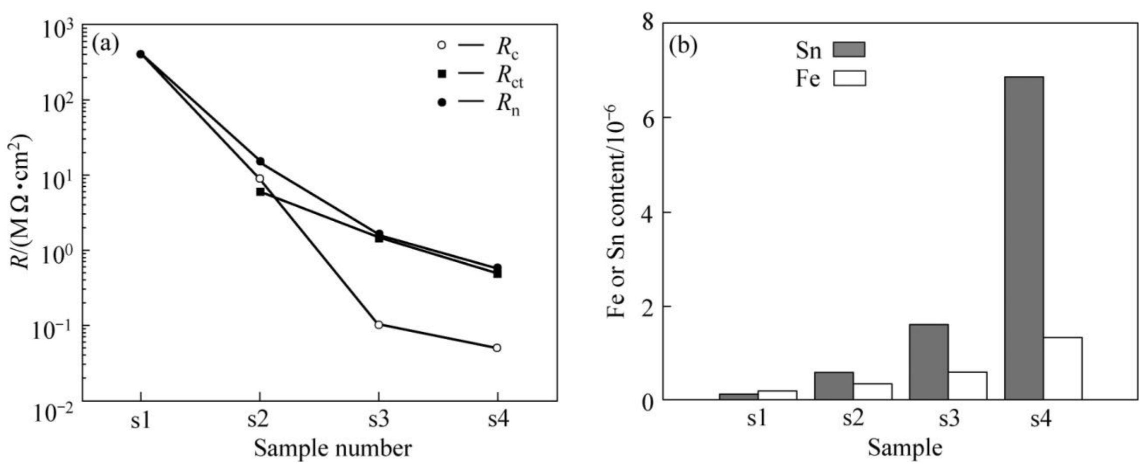

Figure 4 (a). Correlation between electrochemical parameters (noise resistance R_n, coating resistance R_c and charge transfer resistance R_{ct} (b) Tin and iron contents in cans.

4. Tin plate corrosion mechanism in aerated and deaerated media

The various researches done on tin plate corrosion oxygen play a very important role in this process. Tin plate corrosion is basically dependent on the nature of electrolyte to which it is exposed. Deaerated systems decreases the corrosion resistance whereas aerated systems increases the corrosion resistance. The large increase in polarization resistance and cathodic resistance in the aerated solutions proves to be a good inhibitor in the presence of oxygen. Bastidas *et al.* [40] analysed four substrates namely pure tin, tin plate, alloy layer and bare steel in citrate solutions (pH=6) in aerated as well as deaerated media with inclusion and exclusion of inhibitor. A sodium salt of alkenyl succinate was employed as an inhibitor. The techniques adopted for carrying out studies were polarization curves, polarization impedance and resistance. The outcomes of the studies revealed that the corrosion inhibitor was active in the aerated media in the case of bare steel. Oxygen was found to be great relevance in tinplate corrosion process. The R_p and R_{ct} values are one degree higher in de aerated media as compared to aerated media. After 10 to 24 hrs time, the increment in R_p and R_{ct} values (with inhibitor) represented a good steel tin inhibitor.

5. Techniques for determination of tin corrosion in canned foods

The metallic dissolution is through internal corrosion in tin cans which involves electro-chemical reactions. Various techniques are being employed for the determination of tin which are discussed below.

5.1

UV/VIS spectrophotometry, which involves testing of tin plate corrosion under the same conditions which will be countered by the inner side of the tin plate after storage of food products [41] conducted a research and found that a combination of some chemicals like nonyl phenoxy polyethoxyethanol (OP), bromopyrogallol red (BPR) and cetyltrimethylammonium bromide (CTAB) had shown absorbtion peak at 304 nm.

5.2

Measurement of Polarization Resistances Sweep, recorded that methods like electrical impedance spectroscopy (EIS). The method of impedance spectroscopy is a powerful tool for investigation of electrical properties of materials and interfaces of conducting electrodes [42], electrical resistance, gravimetric mass loss, quartz crystal microbalance based mass loss *etc*. determine interfacial reaction rates due to corrosion and also determines polarization rates which includes step or sweep, current step or sweep, impedance spectroscopy, electrochemical noise *etc*. Beverage cans (250 ml capacity) were tested using electrochemical sensor and EIS was done.

5.3

Other methods like X-ray fluorescence spectrometry also determine the quality of tin and its behaviour in corrosive media. Y. Mino [43] used X-ray spectrometry with a rhodium X-ray tube to determine tin. Electrochemical sensor (Figure 3) was developed by Da-Hai Zia [44] of three electrodes along with a contactor to connect the electrode to the sensor.

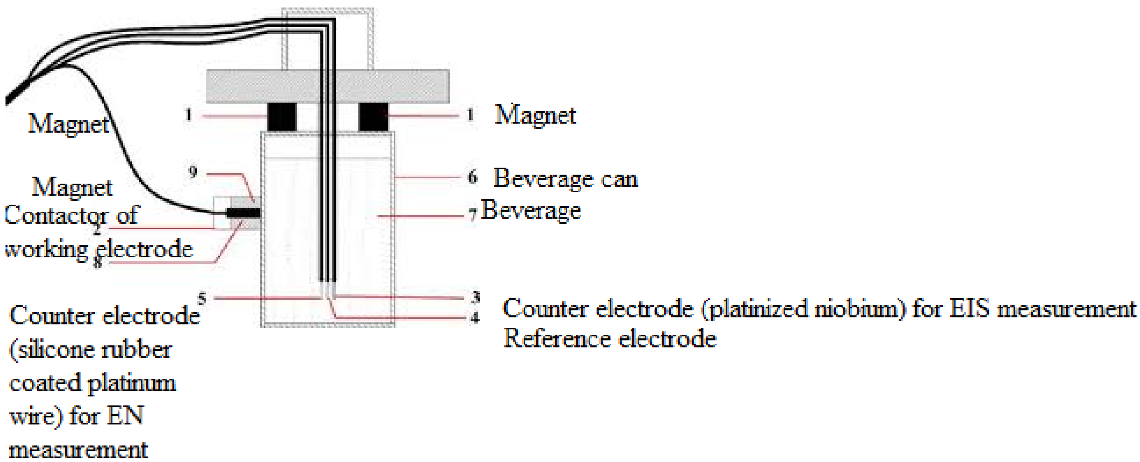

Figure 5. Electrochemical sensor for corrosion detection.

6. Various corrosion inhibitors for tin can corrosion

The Table 1 below represents the various corrosion inhibitors used in different media like HCl, HNO_3, NaCl, citric acid, tartaric acid *etc*. Weight loss, polarization techniques, thermometric techniques, FTIR and NMR spectroscopy, EIS were used in the analysis of corrosion mechanism and inhibition. A variety of corrosion inhibitors like essential onion oil, dioctyl sebacate oil, epoxy phenolic lacquers, natural honey and black radish juice, cerium, sodium lauryl sulphate *etc*. were used and showed respective corrosion inhibition efficiencies at different conditions.

Table 1. Various corrosion inhibitors used in different corrosive medium.

S.No	Medium	Inhibitor used	Method	Ref.
1	NaCl solution	Essential onion oil dioctyl sebacate oil epoxy phenolic lacquers	Weight loss and polarization	[45]
2	NaCl solution	Cerium	EIS	[46]
3	Cirtic acid	Arginine, lysine, cysteine hydrochloride	Weight loss and EIS	[47–49]

S.No	Medium	Inhibitor used	Method	Ref.
4	NaCl solution	Natural honey and black radish juice	Weight loss and polarization techniques	[50]
5	NaCl solution	Bioorganic tomato peel	FTIR and NMR spectroscopy	[51]
6	Tartaric acid	*Azadirachta indica*	EIS	[27]
7	HCl and HNO_3	Carrageenan compounds	Weight loss and thermometric techniques	[52]
8	Hydrochloride solution (0.5 M HCl)	Natural *artemisia* oils	Potentiostatic polarization	[53]
9	0.5 M HCl solution	*Thymus satureioides* (TS) oil	Potentiodynamic polarization and polarization resistance measurements	[54]
10	Nitrates	Sodium lauryl sulphate	Acid products	[55]
11	Anaerobic corrosion	Chrysanthemin victoria plums and raspberries	EIS	[56]
12	NaCl solution	Amino acids and vitamin C	EIS	[57]
13	Fruit juices	Additives	Scanning Electron Microscopy (SEM)	[3]
14	Citric chloride solution	Amino acids	EIS	[58]
15	NaCl	Polyacrylamide	Polarization technique	[59]

7. Various research reports on use for various inhibitors

A.N. Grassino *et al.* did a research and found that the use of Essential Onion Oil (EOO) improves the protects the tinplate as compared to dioctyl sebacate oil (DOS), and was found to be as effective as epoxy phenolic lacquers. The addition of EOO was recommended by the researchers due to the cost of canned food being economical and also with regards to enhanced organoleptic properties maintaining a temperature lower than 36°C [45]. Scanning electron microscopy (SEM) and energy dispersive spectroscopy analysis were performed and they revealed that location of cerium precipitates totally depend on the distribution of the cathodic areas that may form a continuous layer over the surface it may precipitate in the mechanical failures. This analysis was carried out by M.A. Arenas *et al.* [46].

M.A. Quraishi *et al.* [47–49] found that nitrogen containing amino acids show great inhibition efficiency of about 70% at 5 ppm and sulphur containing amino acids 69% and 56% efficiency at 50 ppm concentration respectively. Effect of natural honey (chestnut and acacia), as well as natural honey with black radish juice on tin can corrosion in NaCl and aqueous media by using weight loss and polarization techniques. The study revealed that inhibition efficiency of acacia honey had a lower value than that of chestnut honey, while the addition of black radish juice augmented the inhibition efficiency of both honey varieties. A multi-layer adsorbed film was formed on the surface of tin [50]. Pectin is an efficient corrosion inhibitor having efficiency of about 73% even at lower concentrations, far better than commercially available pectin. As far as chemical profile, rheological properties and structural characterisation of extracted pectin is concerned, tomato peel prove to be a suitable source for pectin isolation. Furthermore results compiled show that under-utilised biomass waste from tomato canning industry can be applied for development of new generation of corrosion inhibitors [51].

L. Bammou *et al.* [52] analysed the behaviour of corrosion of tin plate in HCl and addition of natural *Artemisia* essential oil at different concentrations and temperatures. Some observations were that increase in temperature stimulated the corrosion of tin in HCl. Addition of AO caused reduction of corrosion of tin plate. As the concentration of AO was increased, the corrosion inhibiting efficiency also increased. The best value of inhibition efficiency was 81% at a temperature of 298 K at 0.5 g/l AO concentration. The inhibitor adsorption completely follows Langmuir isotherm [53]. *Thymus satureioides* (TS) oil can be used as an effective green corrosion inhibitor in HCl medium. At 6 g/l concentration the inhibition efficiency was found to be 87%. At higher temperatures (65°C) the inhibition efficiency drops to 75% [54].

Sodium lauryl sulphate is found to have a strong inhibiting effect at a concentration of 5 ppm. The effect of nitrate was squashed at 30 ppm concentration. The anionic surfactants caused negative potential and promoted corrosion inhibition whereas cationic surfactants promoted corrosion of tin. J.C. Sherlock [55] studied the behaviour of surfactants on the dissolution of tin. The addition of anionic surfactants created a negative shift of potential and inhibited corrosion but cationic surfactant caused a positive shift and stimulated corrosion. Further, the role of sodium lauryl sulphate was also investigated at a concentration of 5 ppm and at 30 ppm, it showed a strong inhibitive effect. The presence of surfactant also suppressed the accelerating effect nitrate in tin dissolution.

The extract of Victoria plums and raspberries contains a major constituent chrysanthemin, the main colouring matter, it had been found to act as a cathodic depolarizer for the corrosion of tin by citric and maleic acids [56]. Amino acids like glycine, serine [57], methionine, vitamin C and some other binary mixtures mitigated the dissolution of tin in 3.5% NaCl solution. The presence of 50–100 mM glycine and methionine showed improvement in passive behaviour of tin, while serine also inhibited tin dissolution but in comparison at a higher concentration *i.e.* at 100 mM. Methionine showed a better protection of tin than cystenine and vitamin C. The potential-current curves of tin in a de-aerated solution of citric-chloride solution (pH=5) showed that the cathodic reaction was controlled by the reduction of proton and also a metal–inhibitor complex Sn-H_{cit} was being formed. It was revealed that arginine proved to be the best inhibitor among the studied compounds. Arginine in the concentration range of 10^{-2} M proved to be an effective corrosion inhibitor with 81% inhibition efficiency and behaved as cathodic inhibitor [58].

Two polymers [59] *i.e.* polyacrylamide and polypropenoyl glycine were investigated by *et al.* using potentiodynamic polarization technique. Three samples of polyacrylamide having different molecular weights were being tested at (0.5 to 30) ppm concentrations at 20°C in 1 M NaCl sol. On the other hand, one sample of polypropenoyl glycine having same degree of polarization as that of one sample of polyacrylamide having lowest molecular weight. The results showed that among the 3 samples of polyacrylamide, the sample having lowest molecular weight showed the highest inhibition efficiency, and the sample having highest molecular weight accelerated the rate of corrosion of tin can. Same case was for the polypropenoyl glycine sample as its molecular weight was also very low like the one showing good inhibition efficiency.

8. Conclusions

This entire review makes it clear that tin dissolution mostly take place when it comes on contact with acids present in the canned products, like citric acid, maleic acid, oxalic acid, hydrochloric acid *etc*. Fresh juices do not cause large amount of corrosion but juices, beverages and other canned products containing artificial colours and sweeteners accelerate the rate of corrosion. This problem of tin can corrosion can be tackled by the use of various organic as well as inorganic inhibitors as this paper reflects various tests performed under different conditions like SEM, EIS, weight loss *etc*. A wide range of corrosion inhibitors like essential onion oils, dioctyl sebacate oil, epoxy phenolic lacquers, Natural honey and black radish juice, cerium, sodium lauryl sulphate, Natural *Artemisia* Oils, Amino acids *etc*. were used and proved to be effective corrosion inhibitors.

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