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The Ability of the Ever Silver Container to Resist Corrosion when Exposed to the Puli Kulambu Recipe, both with and Without the Addition of Sodium Chloride

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Abstract

The corrosion resistance of Ever Silver (SS 304 alloy) has been assessed through polarization studies while immersed in various environments, including a water system, Puli Kulambu Recipe, Puli Kulambu Recipe + salt (sodium chloride) (5000 ppm) system. This study leads to the following conclusions. LPR values decrease in the following order: Puli Kulambu Recipe > water > Puli Kulambu Recipe + salt Corrosion current values increase in the following order: Puli Kulambu Recipe < water < Puli Kulambu Recipe + salt Corrosion resistance decreases in the following order: Puli Kulambu Recipe > water > Puli Kulambu Recipe + salt These findings imply that, Puli Kulambu Recipe can be stored in Ever Silver without any hesitation when compared with other systems; Puli Kulambu Recipe with salt should not be stored in Ever Silver containers; Officer goers / students should add salt with Puli Kulambu Recipe just before eating.

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Corrosion Resistance; Ever Silver Container; Puli Kulambu Recipe with and Without Sodium Chloride; Polarization Study.

Introduction

Daily, we encounter various cans filled with beverages. These metal containers are transforming the beverage packaging sector. Their elegant design, convenience, and ecological benefits have made them an essential component of our everyday existence. Now, let us explore how these cans are maintaining the Flavors we enjoy.

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Beverage cans, often referred to as drink cans, are metallic vessels specifically engineered to hold a predetermined volume of liquid, including carbonated soft drinks, alcoholic beverages, fruit juices, tea, and other liquids. These containers are widely utilized in the beverage sector for the packaging and distribution of a diverse array of drinks.

The popularity of drink cans surged quickly, attributed to their convenience and ease of transport. Their lightweight and stackable design facilitates mobility, making them ideal for consumption while on the move. Furthermore, drink cans offer excellent preservation and quality retention by shielding the contents from light, air, and moisture, thereby ensuring the beverages remain fresh and flavorful.

The prevailing trend involves the utilization of steel and aluminium in the production of containers. Numerous studies have been conducted regarding the containers utilized for the storage of beverages and food products.[1-10]

Corrosion resistance of passive films on different stainless steel grades in food and beverage industry has been undertaken by Santamaria *et al.*,[1] Passive films were grown on 304 L, 316 L and Duplex stainless steels by immersion at open circuit potential in solutions mimicking food and beverage industry environments. In acidic food stainless steel surfaces are covered by Cr rich passive films, and generalized dissolution occurs on their surface with consequent ions release into the electrolyte.

Study of corrosion resistance of Stainless Steels for food and beverage industry has been investigated by Tranchida *et al.,*[2] who have performed the physico-chemical characterization of passive films grown on different stainless steel grades after long exposure time in hot purified water (HPW). In order to get more insight into dissolution phenomena that can induce rouging on equipment materials typically involved in food and beverage industries, 304L, 316L and a super duplex 2507 SS samples were passivated at the open circuit potential by different immersion times in HPW at 60°C. Photoelectrochemical and Electrochemical Impedance measurements were performed in the attempt to correlate the electronic properties of the passive films (band gap and conductivity type) to their corrosion resistance.

Santamaria *et al.,*[3] have reported that Austenitic stainless steels qualify for processing and packaging applications in the food and beverages industry due to their excellent corrosion resistance and hygienic properties. Nevertheless, poor tribological behavior has limited the use in applications where corrosion and wear resistance are required.

Chang *et al.,*[4] have reported that Tinplate containers with high strength, good formability and corrosion resistance, has been widely used in food, beverages, grease, chemicals and other applications. In recent years, because of the significantly progress of tinplate container manufacturing technology, many tinplate cans have been opened in easy-open rings. However, a large number of food cans still use can openers as an important tool for opening cans.

It has been reported by Mareci *et al.*,[5] that Austenitic stainless steel alloys are used in different food industry applications, including the preparation and storage of acidified carbonated soft drinks. Yet, austenitic stainless steels are not inert materials in contact with these drinks, and eventual modifications of these alloys must be investigated.

Rossi *et al.*,[6] have reported that AISI 304L stainless steel is widely used in the processing equipment and food and beverage handling industries due to its corrosion resistance, hygienic properties, and cost-effectiveness. However, it is prone to pitting and crevice corrosion phenomena, the development of which can be influenced by factors such as chloride concentration, temperature, humidity, and bacterial presence. Surface treatments, including roughness levels and residual tensile stress, can significantly affect the corrosion behavior and resistance of the material.

It has been reported by Baeghbali *et al.,*[7] that vats, vessels, and tanks are used in various industries for the storage, transport, and processing of liquids. In this chapter, after an introduction to food industry storage equipment mainly being vats, vessels, and tanks, the different types and applications of these equipment for various types of liquids in the food industry are discussed. These applications include the dairy industry, edible oil industry, beverages industry, as well as traditional and industrial tanks, vats, and vessels used in various food processing operations.

Hossain has reported8 that the corrosion resistance of stainless steels, in combination with their good mechanical properties and manufacturing characteristics, makes them an extremely valuable and flexible material for designers. The most dominant product form for stainless steels is cold rolled sheet and the major application areas include consumer products and plant and equipment for the oil and gas, chemical process, and food and beverage industries. Within this context surface of stainless steel equipment components and tube systems must fulfill the process requirements. The most important function must be corrosion resistance, neutral, easy to clean etc.

After 18 months in service, localized corrosion pits were observed on stainless-steel products used in the food- and beverage-processing environments of a snack bar. Steiner Petrovič and Mandrino have investigated whether the observed corrosion of the austenitic and ferritic stainless steels AISI 304 and AISI 430, respectively, could be caused by the improper maintenance of the steel surfaces. To check for the presence and identity of possible corrosive agents in an aggressive cleaner, surface-sensitive Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS) of the steel surfaces were performed.[9]

Friedrich *et al.,*[10] have reported that Austenitic stainless steels qualify for applications in the food and beverages industry due to their good corrosion resistance, inertness, cleanability and hygienic properties. Nevertheless poor tribological behavior, especially low abrasive/adhesive wear resistance and a tendency to fretting, has prevented the use of these materials in applications where both corrosion and wear resistance are required. Low temperature carburising or nitriding has offered a solution to enhance mechanical properties without altering the corrosion resistance.

Objective of the Present Study

Can Puli kulambu recipe be stored in ever silver vessels? That is the question before us. To answer this question the present work in undertaken. The corrosion behavior of Ever Silver (SS 304 alloy) has been assessed in three different environments: water system, Puli kulambu system, and Puli kulambu system + salt (sodium chloride 5000 ppm) utilizing AC impedance spectroscopy

Methods and Materials

This section outlines the experimental methods and materials employed in the study.

Puli Kulambu Recipe

Puli in tamil means 'tamarind' and Kuzhambu means 'curry / gravy'. So puli kuzhambu means gravy using tamarind, vegetables like ladies finger.

Puli Kulambu is one of the most popular tangy South Indian curries that serves as a great side dish for rice. We make Puli Kulambu to go with rice for lunch and use the leftover as a side dish for idli, dosa for dinner.[11]

Ever Silver Composition

Ever Silver was sourced from the vessel markets. Ever Silver is also known as SS 304.[12-15]

Composition SS 304

The constituents of SS 304 (Stainless Steel 304) are as follows

Chromium (Cr): 18-20%; Nickel (Ni): 8-10.5%; Carbon (C): Maximum 0.08%; Manganese (Mn): Maximum 2%; Silicon (Si): 0.75%; Phosphorus (P): Maximum 0.045%; Sulfur (S): Maximum 0.03%

Electrochemical Study

Polarization Study

A three-electrode cell setup was utilized to acquire polarization curves. Different test solutions, such as water system, Pulikulambu recipe system, and Pulikulambu recipe + salt (sodium chloride- 5000 ppm) system were tested with the Ever Silver electrode. Polarization investigations were carried out using a CHI 660A electrochemical workstation. The corrosion resistance of the Ever Silver electrode was evaluated while submerged in the various test solutions. The configuration included a working electrode composed of Ever Silver, a saturated calomel electrode (SCE) functioning as the reference electrode, and a platinum counter electrode (refer to Figure 1).

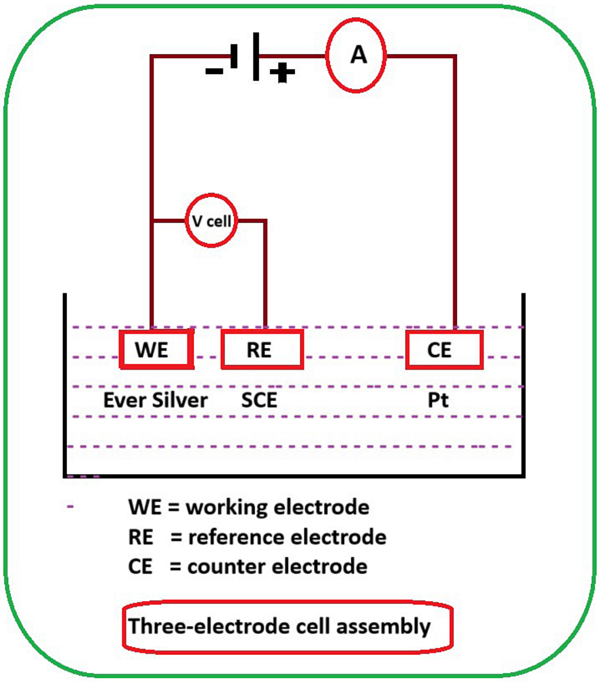

Fig. 1: Three-electrode cell assembly

Results

The corrosion resistance of Ever Silver (SS 304 alloy) has been assessed through polarization studies while immersed in various environments, including a water system, Puli Kulambu Recipe, Puli Kulambu Recipe + salt (sodium chloride) (5000 ppm) system.

The resulting polarization curves are illustrated in Figures 2-4. Key corrosion parameters, including corrosion potential, Tafel slopes (βc for cathodic and βa for anodic), linear polarization resistance (LPR), and corrosion current values, are presented in Table 1. A comparative analysis of these values is depicted in Figures 5-7. It is widely recognized that in polarization studies, an increase in corrosion resistance corresponds to a rise in LPR values and a decrease in corrosion current, as shown in Figure 8.[16-20]

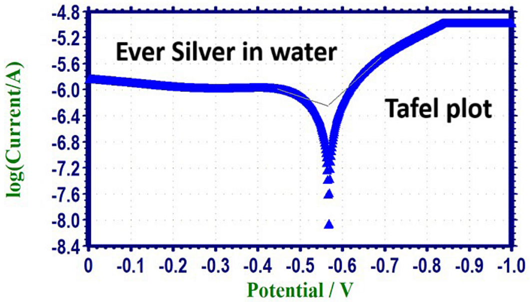

Fig. 2: Polarization curve of Ever Silver immersed in water

Table 1. Corrosion parameters of Ever Silver (ES) (SS 304) immersed in various test solutions obtained from polarization study Puli Kulambu Recipe

System	E_{corr} mV vs SCE	β_c mV / decade	β_a mV / decade	LPR Ohmcm²	I_{corr} A/cm²
water	-567	168	454	61698	8.638×10^{-7}
Puli Kulambu Recipe	-66	172	242	123699	3.541×10^{-7}
Puli Kulambu Recipe + salt	-686	137	274	43025	9.243×10^{-7}

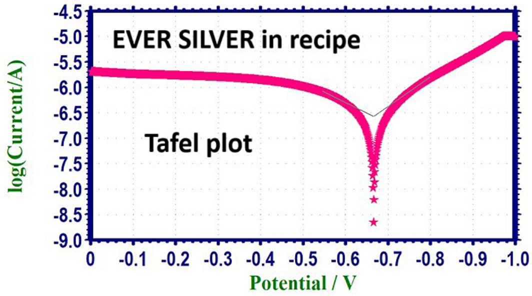

Fig. 3: Polarization curve of Ever Silver immersed in Puli Kulambu recipe

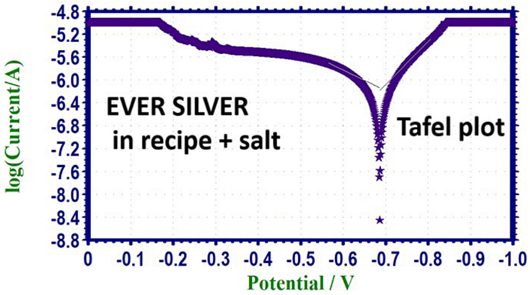

Fig. 4: Polarization curve of Ever Silver immersed in Puli Kulambu recipe + Sodium chloride

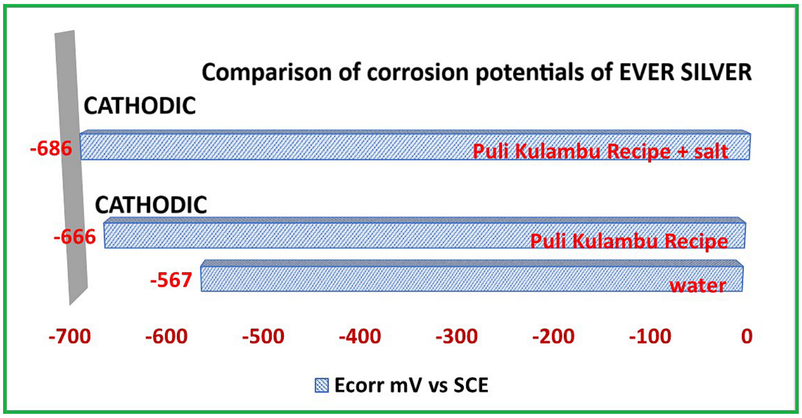

Fig. 5: Comparison of corrosion potentials of Ever Silver in various systems

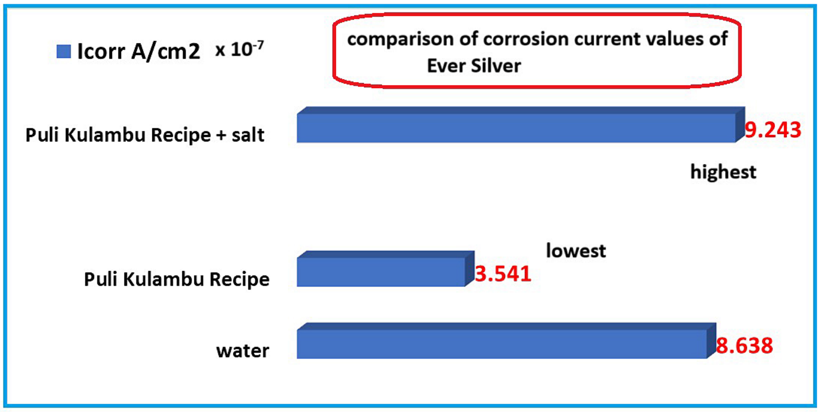

Fig. 6: Comparison of corrosion current values of Ever Silver in various systems

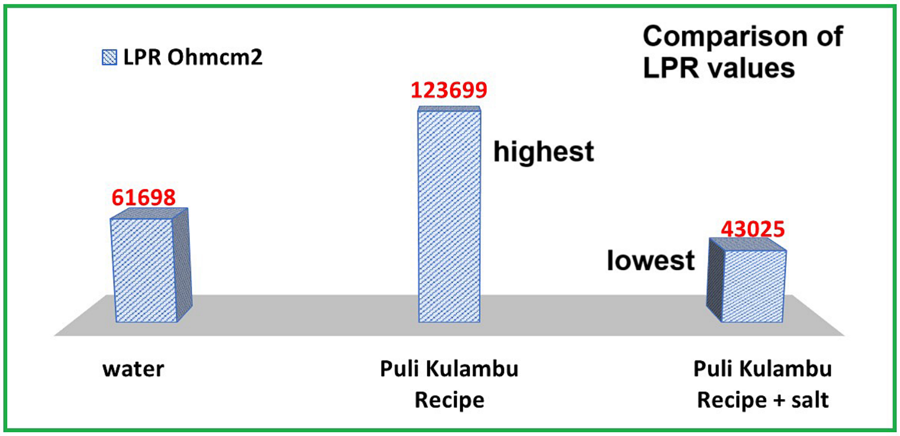

Fig. 7: Comparison of LPR values of Ever Silver in various systems

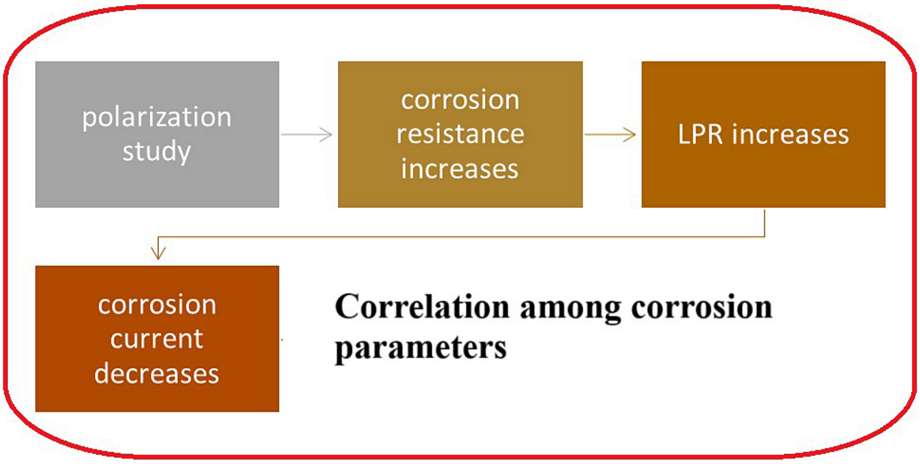

Fig. 8: Correlation among corrosion parameters of polarization study.

Discussion

Ever Silver Immersed in Various Systems

Ever Silver Immersed in Water System

When Ever Silver is immersed in water the corrosion potential is -567 mV vs SCE. The LPR value is 61698 Ohmcm^2. Corrosion current is 8.638 x10^{-7} A/cm^2.

Ever Silver Immersed in Puli Kulambu Recipe System

When Ever Silver is immersed in Puli Kulambu Recipe system, the LPR value increases and corrosion current decreases. This indicates that the corrosion resistance increases. The active principles of the Puli Kulambu Recipe system would have been adsorbed on the metal surface. It implies that Puli Kulambu Recipe can be stored in Ever Silver vessels.

Ever Silver immersed in Puli Kulambu Recipe + salt (Sodium Chloride) (5000 ppm) system.

When Ever Silver is immersed in Puli Kulambu Recipe + salt (sodium chloride) (5000 ppm) system, the LPR value decreases and corrosion current increases. This indicates that the corrosion resistance decreases. This may be due the corrosive nature of chloride ions.

It implies that Puli Kulambu Recipe containing salt (sodium chloride) should not be stored in Ever Silver vessels.

Polarization Study Leads to the Following Conclusions

For Ever Silver system

LPR values

LPR values decrease in the following order.

Puli Kulambu Recipe > water > Puli Kulambu Recipe + salt

Corrosion Current Values

Corrosion current values increase in the following order.

Puli Kulambu Recipe < water < Puli Kulambu Recipe + salt

Implication

Puli Kulambu Recipe can be stored in Ever Silver without any hesitation when compared with other systems.

Conclusion

- Puli Kulambu Recipe *can be stored in Ever Silver without any hesitation when compared with other systems*
- Puli Kulambu Recipe with salt should not be stored in Ever Silver containers
- Officer goers / students should add salt with Puli Kulambu Recipe just before eating.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Susai Santhammal Rajendran, Caslav Lacnjevac:** Conceptualization, Methodology, Writing – Original Draft.
- **P Arul Deepa, D Delphin, M Harthika, V Pappathi, A Preethi Christina, T Priyadharshini, R Yuasri, Anitha Nilavan:** Data Collection, Analysis, Writing – Review & Editing.
- **Abdulhameed Al-Hashem, T Umamathi:** Visualization, Supervision, Project Administration.

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