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The choice of container material for storing pomegranate juice: Should one opt for SS 304 alloy or SS 316L alloy?

ABSTRACT

The objective of this research is to examine the feasibility of storing pomegranate juice in containers constructed from SS 304 alloy, commonly referred to as Ever Silver, or SS 316 L alloy. The corrosion resistance of both SS 304 and SS 316L alloy was evaluated across different environments, including a water system, a pomegranate juice system, and a pomegranate juice system with added sugar (5000 g), utilizing AC impedance spectroscopy for measurement. Key corrosion parameters, including charge transfer resistance, impedance, phase angle, and double layer capacitance, were calculated. The findings indicate that SS 316 L alloy exhibits superior corrosion resistance compared to SS 304 alloy across all three systems. Consequently, it is recommended that pomegranate juice and pomegranate juice with sugar be stored in containers made of SS 316 L alloy, which is also applicable to the water system.

Keywords:*corrosion resistance, pomegranate juice, SS 304, SS 316 L alloy, electrochemical study, AC impedance spectra*

1. INTRODUCTION

Daily, we encounter a multitude of cans filled with various beverages. These metal containers are transforming the beverage packaging sector. Their elegant design, functionality, and ecological benefits have made them an essential component of our everyday existence. Now, let us explore how these cans are safeguarding the flavors we hold dear.

Beverage cans, often referred to as drink cans, are metallic vessels specifically crafted to hold a designated amount of liquid, including carbonated soft drinks, alcoholic beverages, fruit juices, tea, and numerous other liquids. These containers are widely utilized within the beverage industry for the packaging and distribution of a diverse array of drinks.The swift increase in the popularity of beverage cans can primarily be attributed to their convenience and ease of transport.

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Their lightweight and stackable design facilitates mobility, making them especially ideal for consumption while on the go. Furthermore, beverage cans offer excellent preservation and quality retention by shielding the contents from light, air, and moisture, thereby ensuring that the drinks remain fresh and flavorful.

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

The study of corrosion resistance in passive films on various grades of stainless steel within the food and beverage industry was conducted bySantamaria et al. [1]. Passive films were developed on 304 L, 316 L, and Duplex stainless steels through immersion at open circuit potential in solutions that simulate the conditions found in the food and beverage sector. In acidic food environments, the surfaces of stainless steel are coated with chromium-rich passive films, leading to generalized dissolution on their surfaces and the subsequent release of ions into the electrolyte.The corrosion resistance of stainless steels employed in the food and beverage industry has been investigated by Tranchidaet al. [2]. They performed a physico-chemical analysis of the passive films that formed on different grades of stainless steel after extended exposure to hot purified water (HPW). To enhance the understanding of the dissolution processes that may contribute to rouging in materials typically used in the food and beverage sectors, samples of 304L, 316L, and super duplex 2507 stainless steel were passivated at the open circuit potential through varying immersion times in HPW at 60°C. Photoelectrochemical and electrochemical impedance measurements were conducted to establish a relationship between the electronic characteristics of the passive films, such as band gap and conductivity type, and their corrosion resistance [2].Austenitic stainless steels have been identified by Friedrich et al. [3] as appropriate materials for processing and packaging applications in the food and beverage industry, primarily due to their excellent corrosion resistance and hygienic properties. Nevertheless, their insufficient tribological performance has limited their use in situations where both corrosion and wear resistance are critical.Tinplate containers are recognized byChang et al. [4] for their remarkable strength, superior formability, and corrosion resistance, making them widely employed across multiple industries such as food, beverages, grease, and chemicals. Recent technological advancements in the production of tinplate containers have resulted in the development of numerous cans equipped with easy-open rings. However, a considerable portion of food cans still depends on can openers as an essential means of access [4].Mareci et al.[5] have highlighted that austenitic stainless steel alloys are utilized across multiple sectors of the food industry, especially in the processing and storage of acidified carbonated soft drinks. Nonetheless, it is crucial to recognize that austenitic stainless steels do not maintain inertness when interacting with these beverages, which calls for additional research into possible modifications of these alloys [5].Friedrich et al. [6] have noted that AISI 304L stainless steel is widely employed in the food and beverage industry as well as in processing equipment, primarily due to its corrosion resistance, hygienic properties, and cost-effectiveness. However, this material is prone to pitting and crevice corrosion, which can be influenced by factors such as chloride concentration, temperature, humidity, and bacterial presence. Furthermore, surface treatments, including variations in roughness and residual tensile stress, can significantly affect the corrosion behavior and resistance of the steel.Baeghbali et al.[7] have highlighted the critical functions of vats, vessels, and tanks across various industries, particularly in the storage, transportation, and processing of liquids. This chapter commences with a comprehensive overview of the storage equipment employed in the food industry, with a primary emphasis on vats, vessels, and tanks. It then delves into the different types and applications of this equipment tailored to various liquid categories within the food sector. The analysis includes applications in the dairy industry, the edible oil sector, the beverage industry, and the utilization of both traditional and industrial tanks, vats, and vessels in a range of food processing operations.Hossain[8] has noted that the corrosion resistance of stainless steels, combined with their advantageous mechanical properties and manufacturing characteristics, makes them an exceptionally valuable and adaptable material for designers. The most common form of stainless steel is cold rolled sheet, which finds extensive use in consumer products as well as in equipment for the oil and gas, chemical processing, and food and beverage industries. Consequently, the surfaces of stainless steel components and tubing systems must adhere to specific process standards. The foremost requirement is corrosion resistance, along with being neutral and easy to clean. After 18 months of use, localized corrosion pits were detected on stainless-steel products utilized in the food and beverage processing areas of a snack bar.Steiner Petrovic and Mandrino [9] have explored the possible factors leading to corrosion in austenitic and ferritic stainless steels AISI 304 and AISI 430, respectively. Their research emphasizes the role of insufficient maintenance of the steel surfaces as a potential contributing factor. To detect and examine any corrosive agents in an aggressive cleaning solution, they utilized surface-sensitive methods, including Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS), on the steel surfaces.

In a report by Joze Pirs [10], the issue of corrosion damage in a milk tank constructed from stainless austenitic steel is examined, which occurred following a pressure test for tightness utilizing tap water. The analysis indicated that the tank was composed of both coarse-grained and fine-grained steel plate grades, a condition arising from the quenching process after heat treatment. The intergranular corrosion observed in immersion specimens progressed at an uneven rate. This observation bears resemblance to findings in pitting corrosion studies, prompting an effort to analyze the damage through a similar lens.

The Juice of Pomegranate (Punica granatum L.)

Pomegranates [11]are characterized by their low calorie and fat content, while being rich in fiber, vitamins, and minerals. Their advantages encompass antioxidant properties, support for heart health, enhancement of urinary health, improved exercise endurance, among other benefits.

Pomegranates are spherical, crimson fruits (Figure 1) characterized by a white inner pulp filled with crisp, succulent edible seeds known as arils. While they are widely recognized for the vividly colored juice derived from them, these distinctive fruits possess a wealth of additional qualities.

Figure 1.Pomegranate rich in antioxidant [11]

The aim of the current research

The question under consideration is whether pomegranate juice can be preserved in containers constructed from SS 304 or SS 316 L materials. This study seeks to determine which type of container is more appropriate for storing pomegranate juice: one constructed from SS 304 or SS 316 L. The corrosion properties of SS 304 and SS 316 L alloys have been assessed in three different environments: water, pomegranate juice, and pomegranate juice with sugar (5000 ppm) using AC impedance spectroscopy.

2. EXPERIMENTAL

Methods and Materials

This section outlines the experimental methods and materials employed in the research. The aim of this study is to ascertain which alloy, SS 304 or SS 316 L, is more suitable for the storage of pomegranate juice. To address this inquiry, AC impedance spectra have been utilized.

Preparation of pomegranate juice

Fifty grams of pomegranate arils were blended with Dindigul Corporation drinking water using a mixer. The mixture was then filtered to remove any suspended impurities, and the final volume was calibrated to 500 millilitres in a standard measuring flask.

Ever Silver Composition

Ever Silver is an alloy composed of 92.5% pure silver and 7.5% of an additional metal, typically copper. The incorporation of these metals enhances the hardness of the alloy, resulting in a more durable material. Ever Silver was obtained from the vessel markets and is also referred to as SS 304 [12].

SS 316 L alloy

The makeup of 316L stainless steel is mainly comprised of chromium, nickel, and iron. The elevated concentrations of these elements render the alloy resistant to corrosion caused by saltwater and various chemicals. The principal alloying elements, following iron, include chromium (ranging from 16% to 18%), nickel (10% to 12%), and molybdenum (2% to 3%), along with trace amounts of silicon, phosphorus, and sulfur, each constituting less than 1%[13].

3. ELECTROCHEMICAL STUDY

AC impedance spectra

A three-electrode cell setup was utilized to acquire AC impedance spectra. Different test solutions, such as water, lemon juice, and a mixture of lemon juice with salt, were tested with the Ever Silver electrode. The AC impedance spectra were captured using a CHI 660A electrochemical workstation.

The evaluation of the corrosion resistance of the Ever Silver electrode was conducted by immersing it in various test solutions. The setup included a working electrode composed of Ever Silver, a saturated calomel electrode (SCE) utilized as the reference electrode, and a platinum counter electrode, as illustrated in Figure 2.

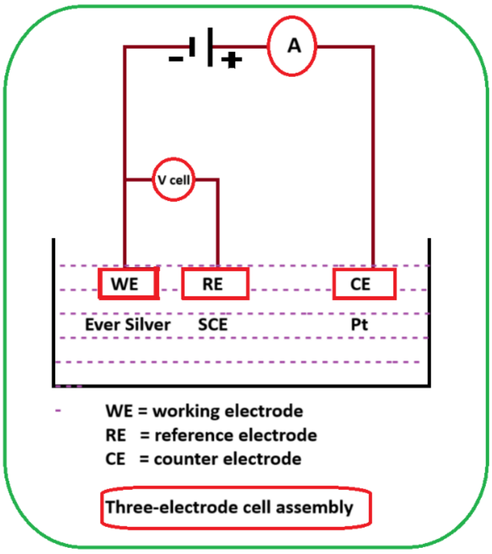

Figure 2. Three-electrode cell assembly

4. RESULTS AND DISCUSSION

The AC impedance spectra have been utilized to evaluate the corrosion resistance of Ever Silver (SS 304) and SS 316 L when submerged in various environments, such as a water system, a pomegranate juice system, and a pomegranate juice and sugar (5000 ppm) system.

A comparative study is conducted to determine which material exhibits greater corrosion resistance in the aforementioned media: SS 304 or SS 316 L. This inquiry is the focus of our investigation.

The AC impedance spectra are depicted in Figures 3-26, and the corrosion parameters are detailed in Table 1. A comparative analysis of these parameters is available in Figures 27-30.

Table 1. Corrosion parameters of SS 304/ SS 316 L alloy immersed in various test solutions obtained from AC impedance spectra

System	Storing vessel	Rct Ohmcm^2	Cdl F/cm^2	Impedance Log(Z/ohm)	Phase angle°
water	SS 304	7656	6.55×10^{-10}	4.332	47.69
	SS 316 L	99790	0.51×10^{-10}	5.513	180
PG juice	SS 304	10293	4.96×10^{-10}	4.379	68.11
	SS 316 L	30821	1.66×10^{-10}	4.712	44.31
PG juice + sugar	SS 304	32871	1.55×10^{-10}	4.726	41.20
	SS 316 L	42100	1.21×10^{-10}	4.996	62.93

An enhancement in the corrosion resistance of Ever Silver is associated with an elevation in charge transfer resistance (Rct), a rise in impedance values, an increase in phase angle values, and a reduction in double layer capacitance (Cdl) (Figure 31).

Implication

It has been noted that SS 316 L exhibits superior corrosion resistance compared to SS 304 in water systems, PG juice systems, and PG juice combined with sugar systems. This indicates that containers constructed from SS 316 L are more suitable for the storage of PG juice[14-20].

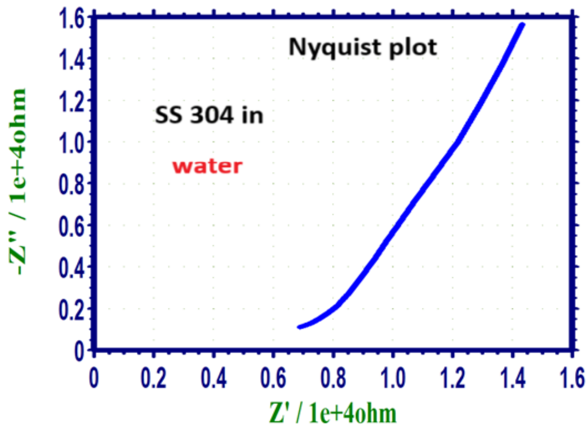

Figure 3. Nyquist plot of SS 304 alloy immersed in water

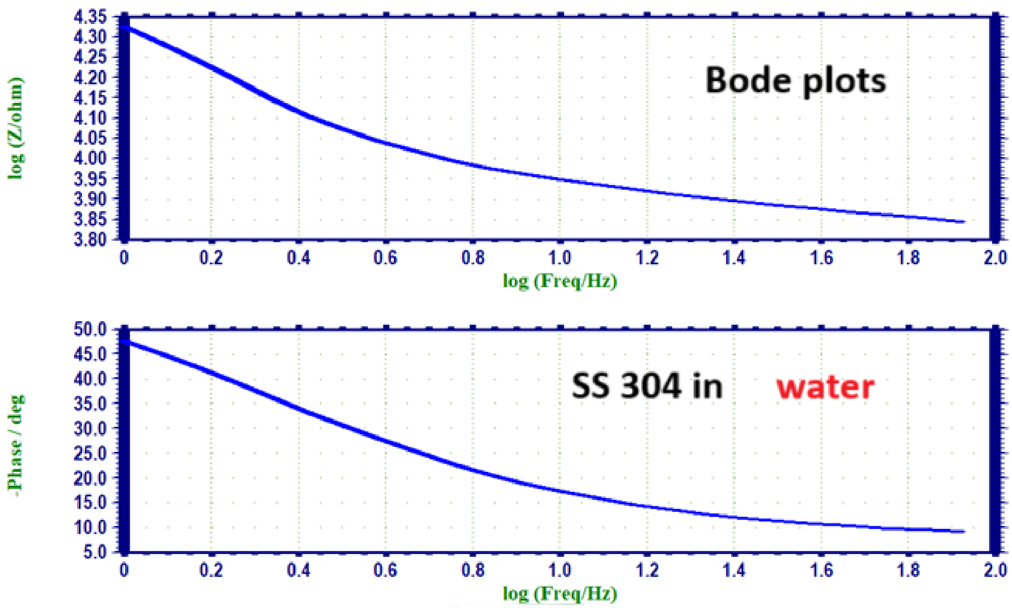

Figure 4. Bode plots of SS 304 alloy immersed in water

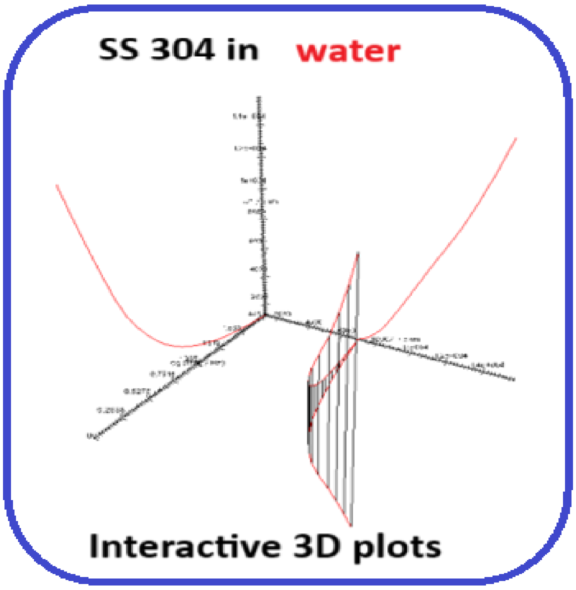

Figure 5. Interactive 3D plots of SS 304 alloy immersed in water

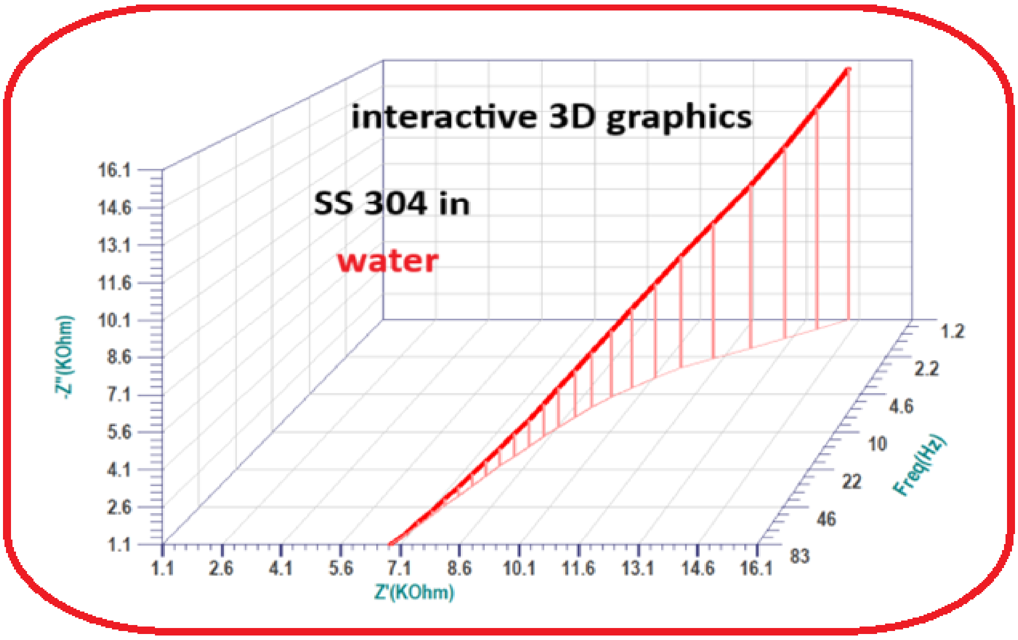

Figure 6. Interactive 3D graphics of SS 304 alloy immersed in water

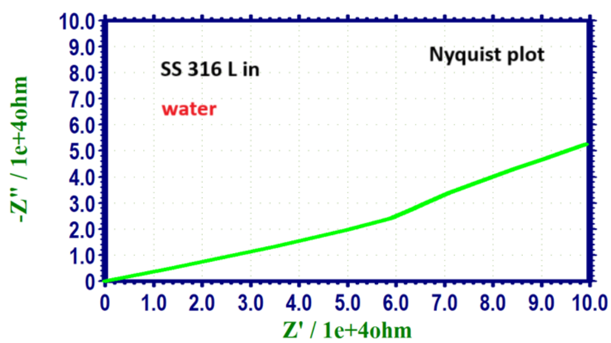

Figure 7. Nyquist plot of SS 316 Lalloy immersed in water

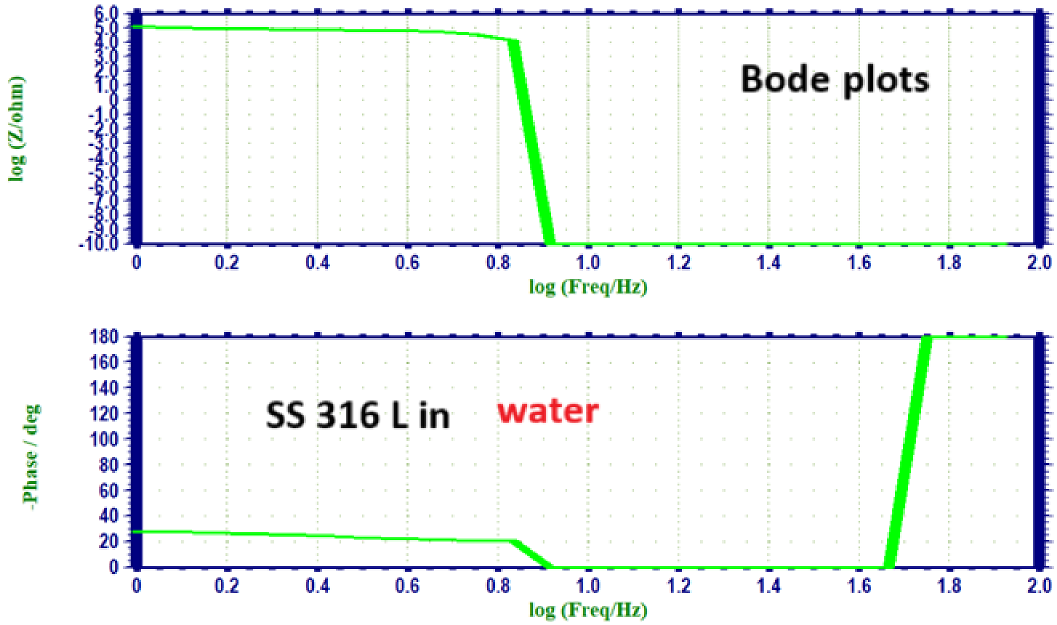

Figure 8. Bode plots of SS 316 Lalloy immersed in water

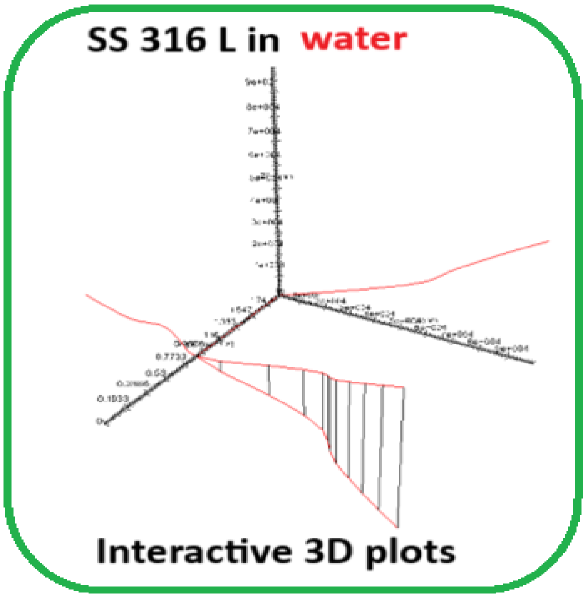

Figure 9. Interactive 3D plots of SS 316 L alloy immersed in water

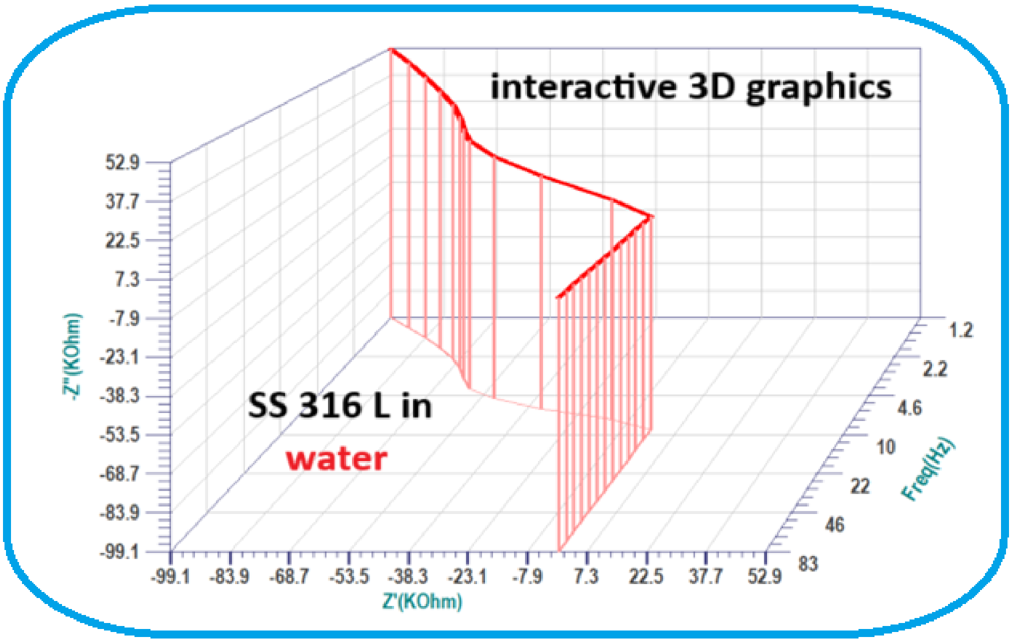

Figure 10. Interactive 3D graphics of SS 316L alloy immersed in water

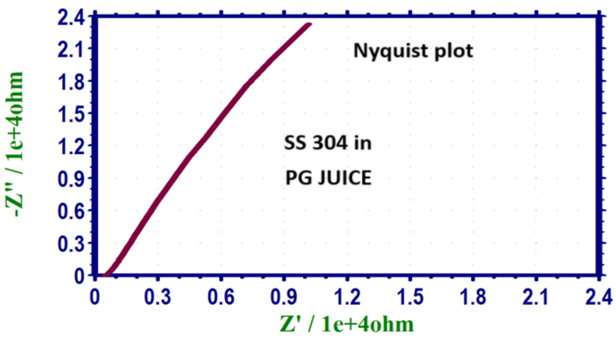

Figure 11. Nyquist plot of SS 304 alloy immersed in PG juice

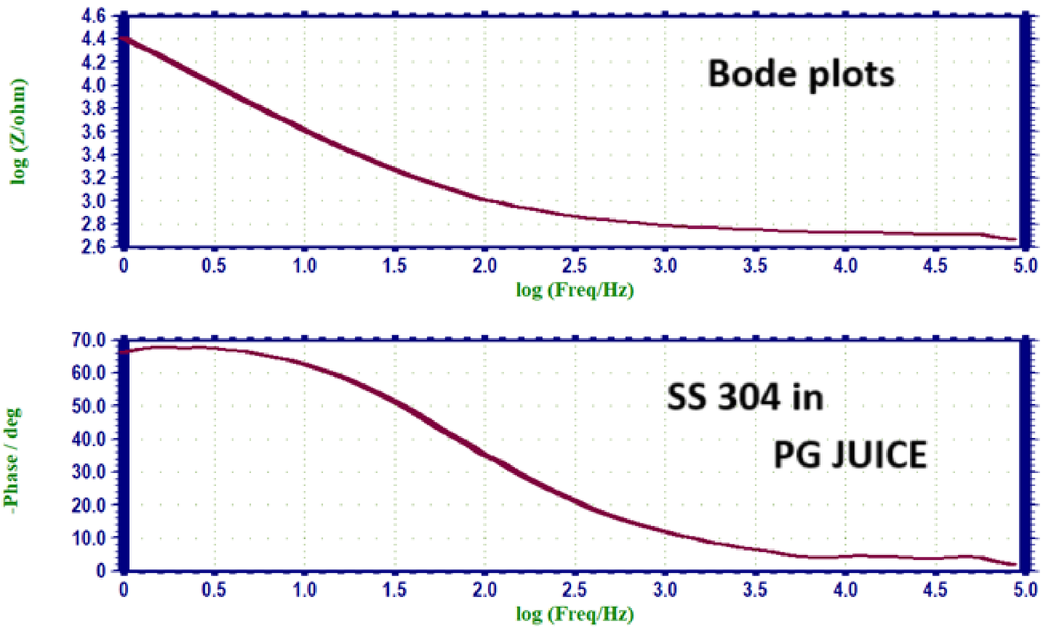

Figure 12. Bode plots of SS 304 alloy immersed in PG juice

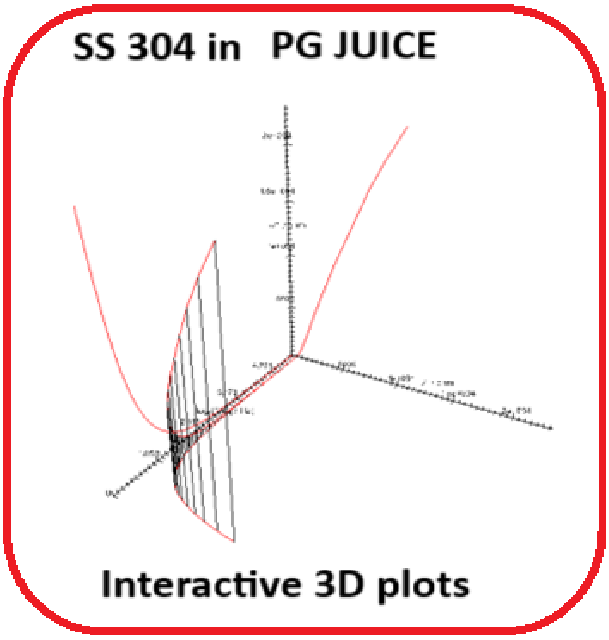

Figure 13. Interactive 3D plots of SS 304 alloy immersed in PG juice

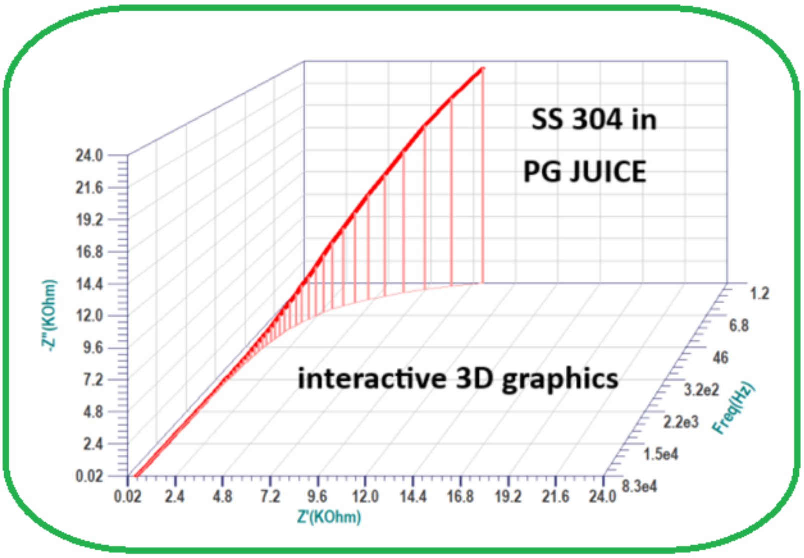

Figure 14. Interactive 3D graphics of SS 304 alloy immersed in PG juice

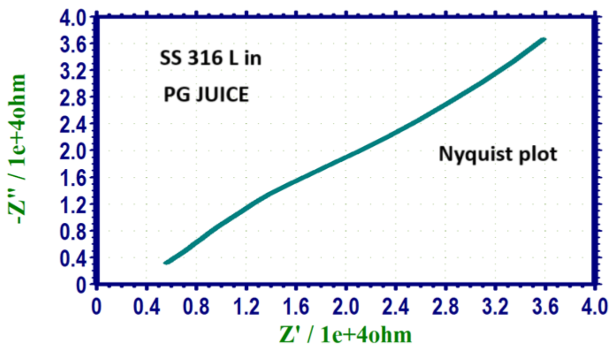

Figure 15. Nyquist plot of SS 316 L alloy immersed in PG juice

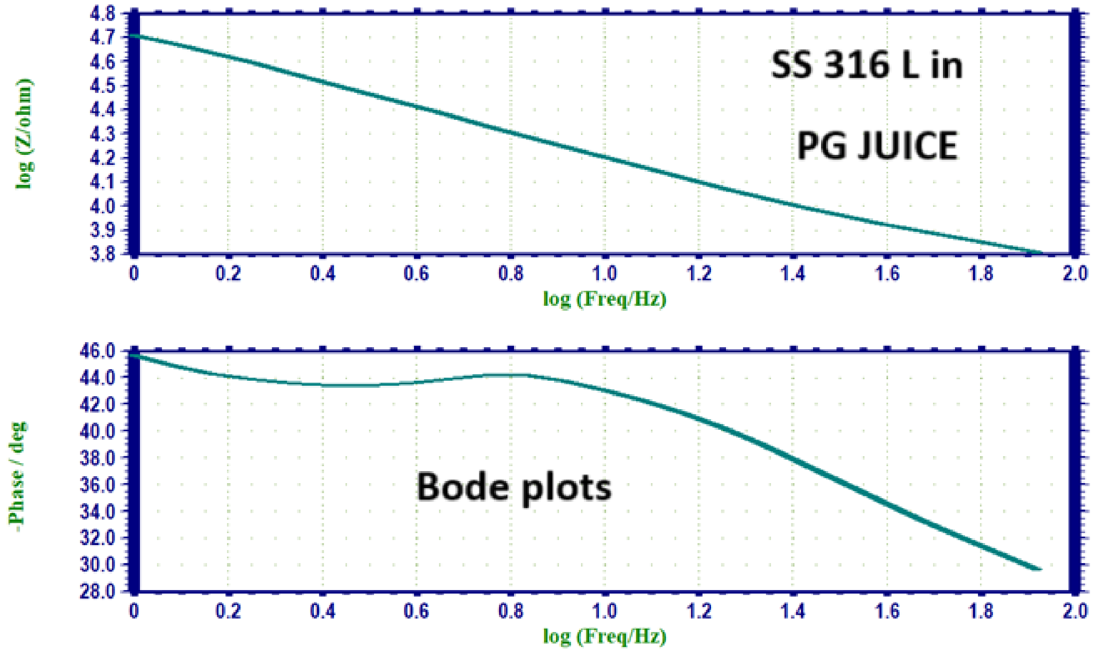

Figure 16. Bode plots of SS 316 L alloy immersed in PG juice

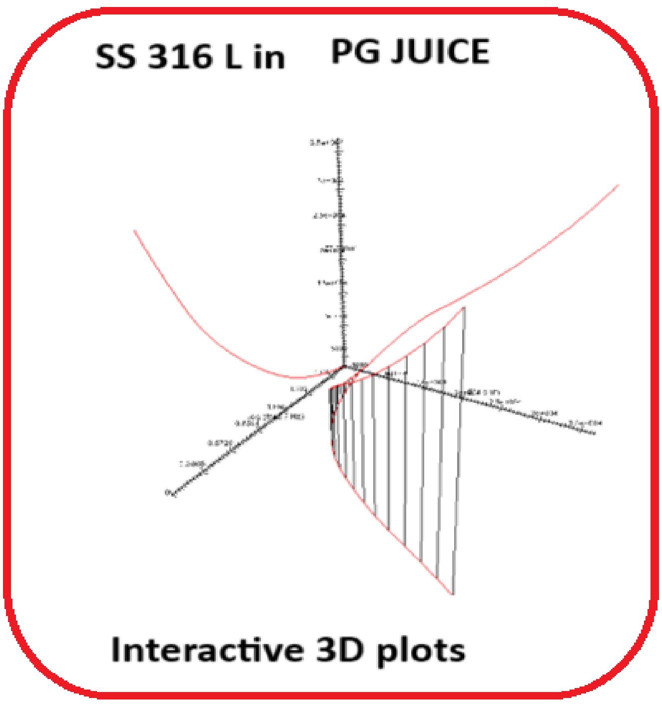

Figure 17. Interactive3D plots of SS 316 L alloy immersed in PG juice

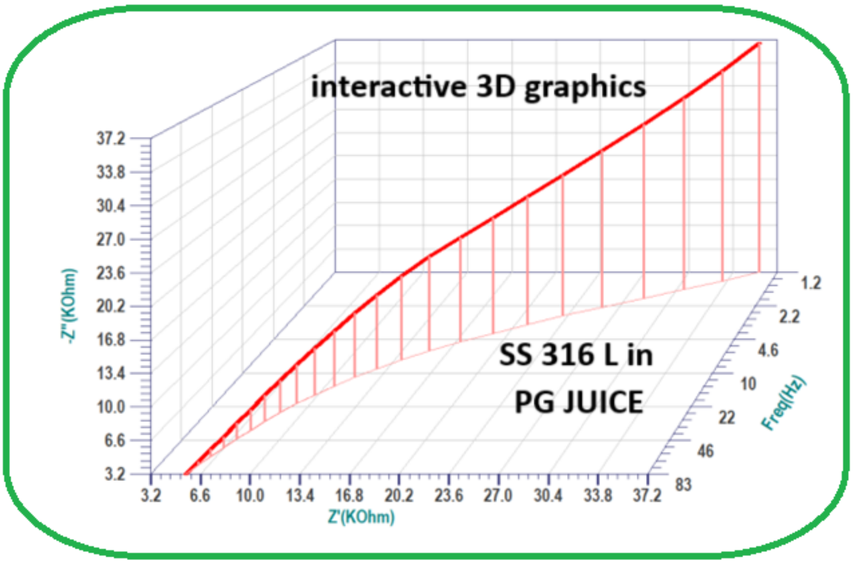

Figure 18. Interactive 3D graphics of SS 316 L alloy immersed in PG juice

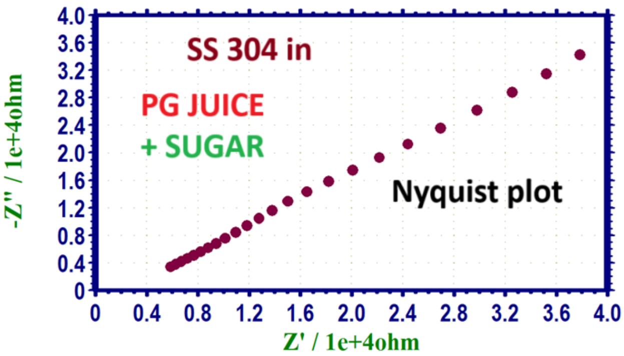

Figure 19. Nyquist plot of SS 304 alloy immersed in PG juice + sugar system

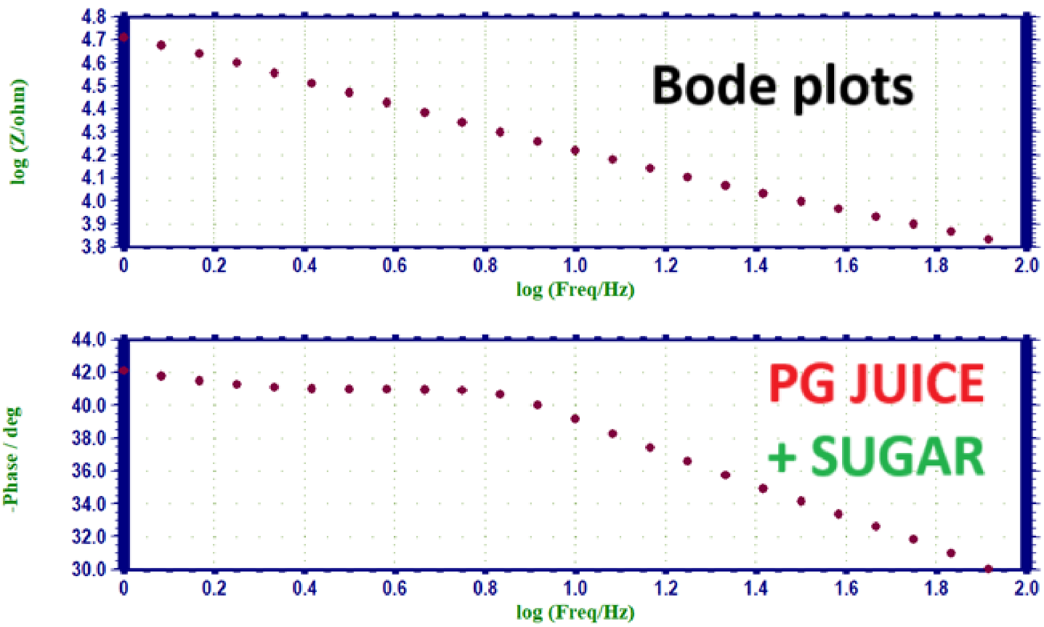

Figure 20. Bode plots of SS 304 alloy immersed in PG juice + sugar system

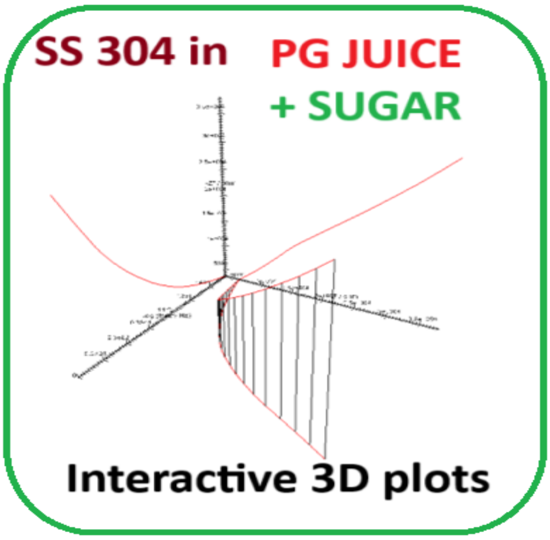

Figure 21. Interactive 3D plots of SS 304 alloy immersed in PG juice + sugar system

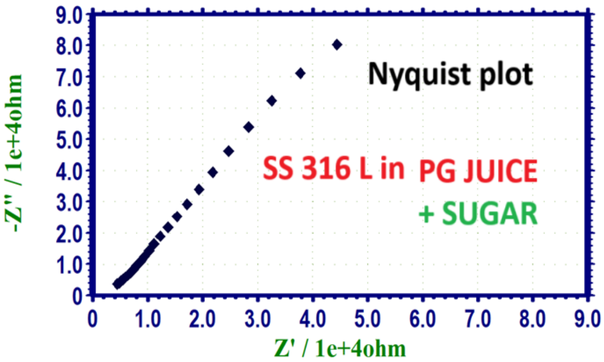

Figure 23. Nyquist plot of SS 316 L alloy immersed in PG juice + sugar system

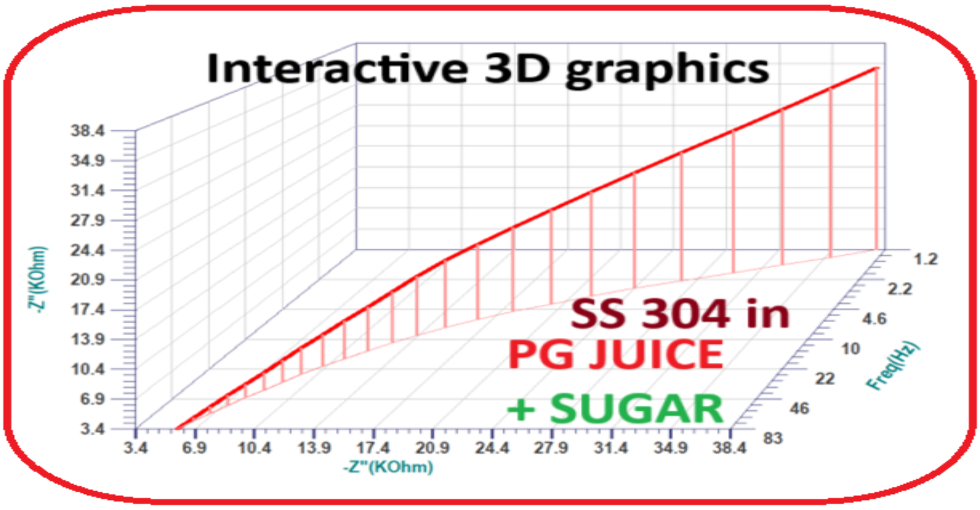

Figure 22. Interactive 3D graphics of SS 304 alloy immersed in PG juice + sugar system

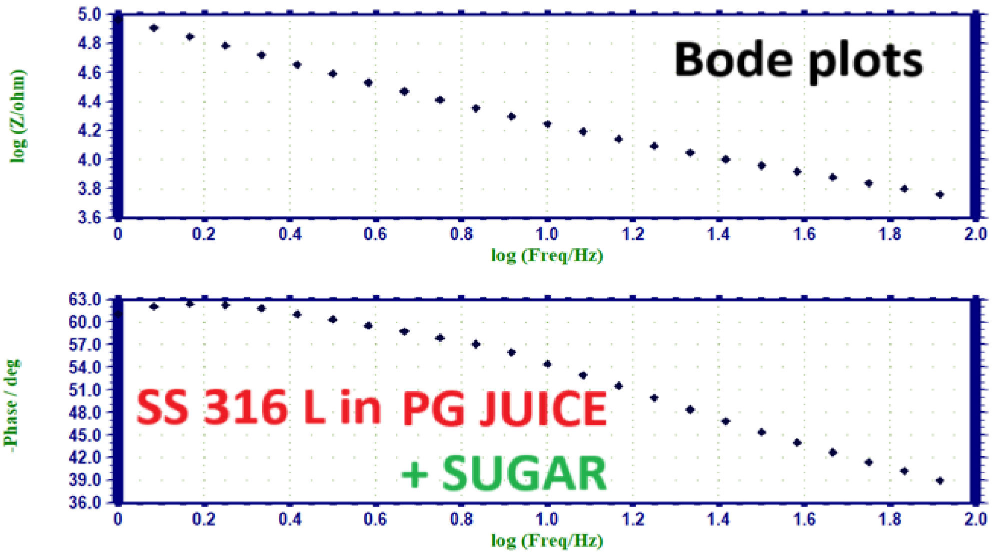

Figure 24. Bode plots of SS 316 L alloy immersed in PG juice + sugar system

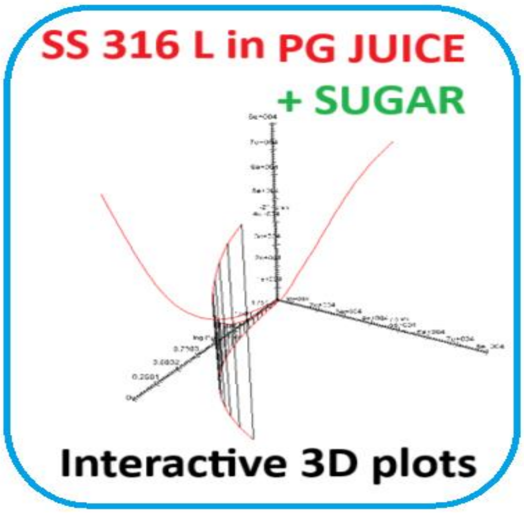

Figure 25. Interactive 3D plots of SS 316 L alloy immersed in PG juice + sugar system

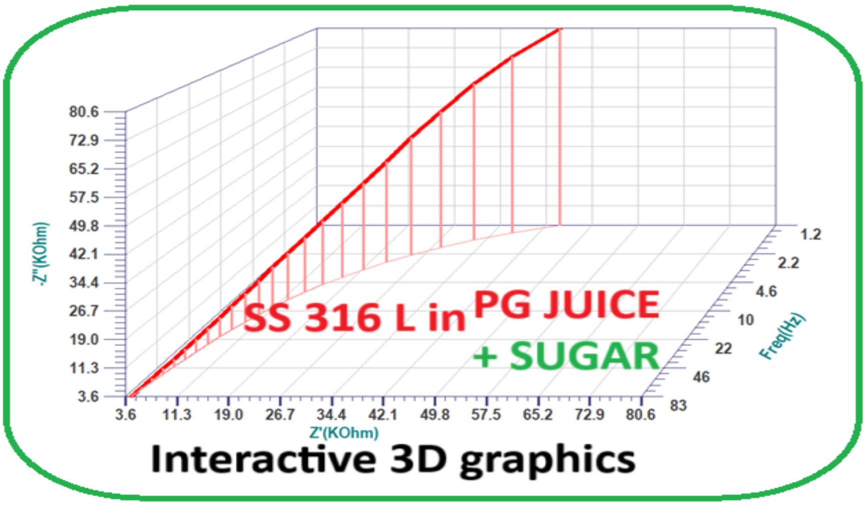

Figure 26. Interactive 3D graphics of SS 316 L alloy immersed in PG juice + sugar system

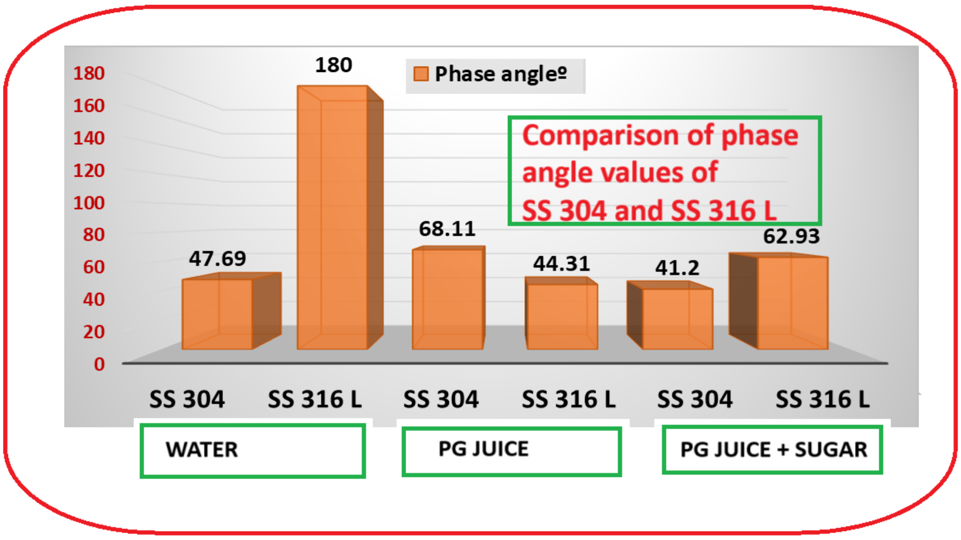

Figure 27. Comparison of phase angle values of SS 304 alloy and SS 316 L alloy

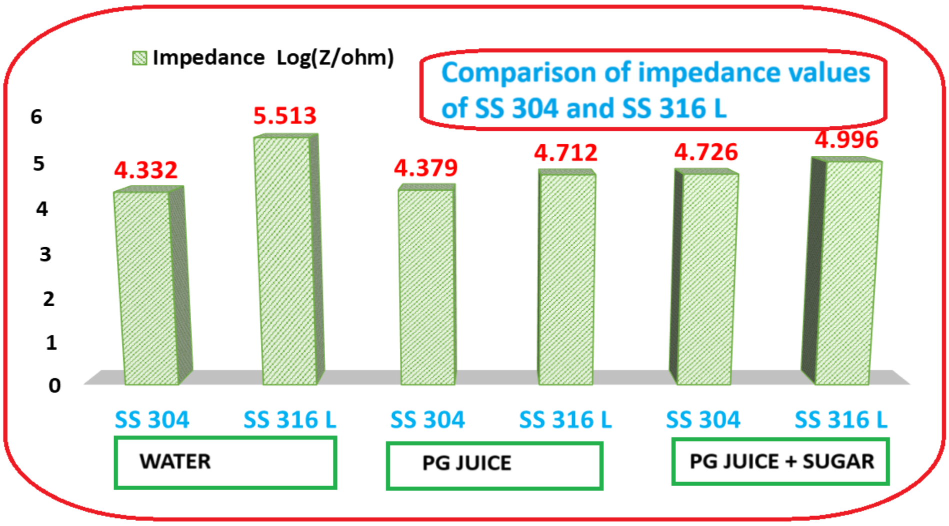

Figure 28. Comparison of impedance values of SS 304 alloy and SS 316 L alloy

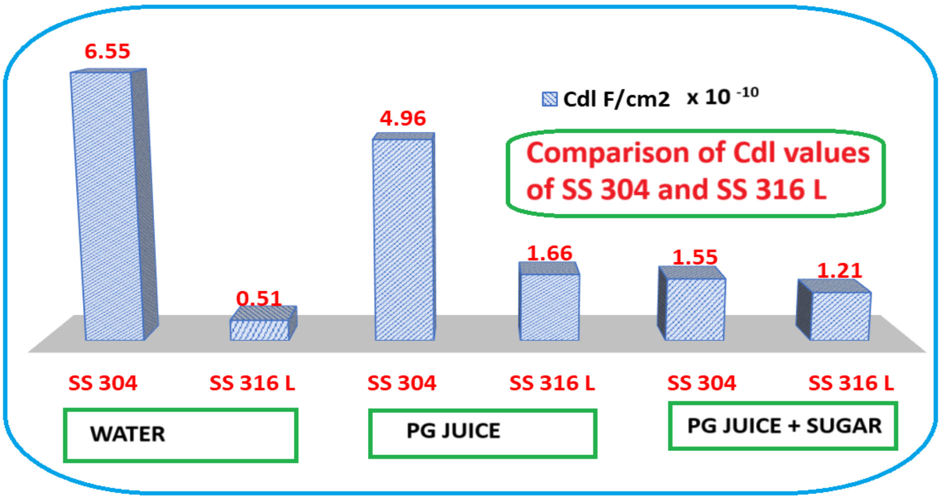

Figure 29. Comparison of Cdl values of SS 304 alloy and SS 316 L alloy

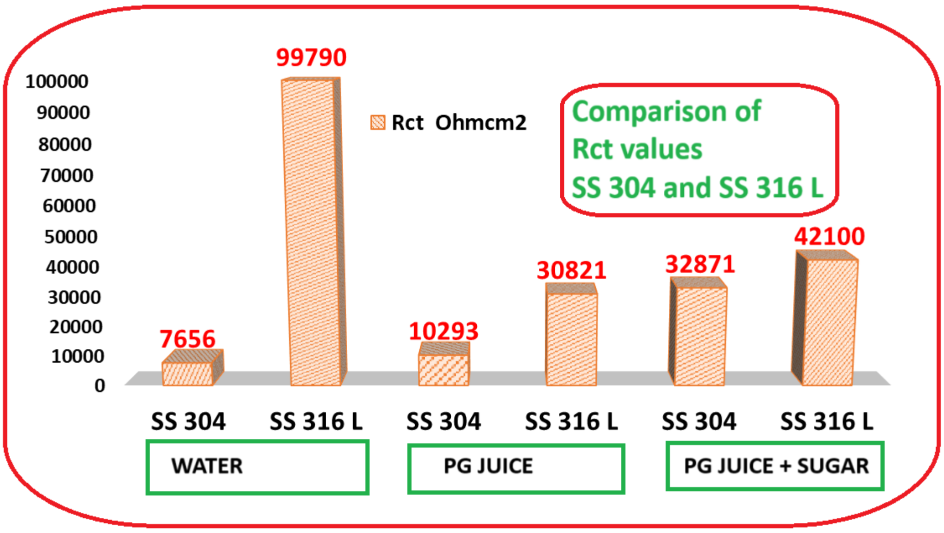

Figure 30. Comparison of Rct values of SS 304 alloy and SS 316 L alloy

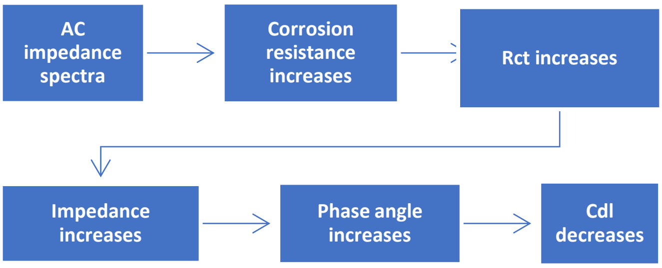

Figure 31. Correlation among corrosion parameters in AC impedance spectra

5. QUALITY DISCUSSION

The conclusions drawn from Table 1 and Figures 3-26 are as follows: as corrosion resistance (protection) improves, the charge transfer resistance also rises. The impedance value increases, and the phase angle value also increases. However, the double layer capacitance value decreases.

The present study has examined the corrosion resistance of three systems, specifically, the corrosion resistance of SS 304 / SS 316 L in water, PG juice, and a PG juice + sugar mixture.

The subsequent points are deduced.

- In water: SS 316 L exhibits greater corrosion resistance compared to SS 304
- In PG juice: SS 316 L demonstrates superior corrosion resistance relative to SS 304
- In a PG juice and sugar system: SS 316 L shows enhanced corrosion resistance over SS 304
- In conclusion, it is advisable to store pomegranate juice in containers constructed from SS 316 L.

Overview and final thoughts

- The objective of this research is to examine the feasibility of storing pomegranate juice in containers constructed from SS 304 alloy, commonly referred to as Ever Silver, or SS 316 L alloy.
- The corrosion resistance of both SS 304 and SS 316 L alloys was evaluated across different environments, including a water system, a pomegranate juice system, and a pomegranate juice system with added sugar (5000 g), utilizing AC impedance spectroscopy for measurement.
- Key corrosion parameters, including charge transfer resistance, impedance, phase angle, and double layer capacitance, were calculated.
- The findings indicate that SS 316 L alloy exhibits superior corrosion resistance compared to SS 304 alloy across all three systems.
- Consequently, it is recommended that pomegranate juice and pomegranate juice with sugar be stored in containers made of SS 316 L alloy, which is also applicable to the water system.

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Authors' contributions

T. Umamathi,Kavipriya Karunaivel, A Preethi Christina, P Arul Deepa, D Delphin, M Harthika, V Pappathi, T Priyadharshini, R Yuasri, Anitha Nilavan, and Caslav Lacnjevac: conceptualization and validation; review and editing.S. Rajendran: writing; correspondence. All authors have read and agreed to the published version of the manuscript.

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IZVOD

IZBOR MATERIJALA POSUDE ZA SKLADIŠTENJE SOKA OD NARA: DA LI SE TREBA ODLUČITI ZA LEGURU SS 304 ILI LEGURU SS 316L?

Cilj ovog istraživanja je da se ispita izvodljivost skladištenja soka od nara u posudama napravljenim od legure SS 304, koja se obično naziva Ever Silver, ili legura SS 316 L. Otpornost na koroziju legure SS 304 i SS 316L je procenjena u različitim okruženjima, uključujući sistem vode, sistem soka od nara i sistem soka od nara sa dodatkom šećera (5000 g), korišćenjem spektroskopije naizmenične impedanse za merenje. Izračunati su ključni parametri korozije, uključujući otpor prenosa naelektrisanja, impedansu, fazni ugao i dvoslojni kapacitet. Nalazi pokazuju da legura SS 316L pokazuje superiornu otpornost na koroziju u poređenju sa legurom SS 304 u sva tri sistema. Zbog toga se preporučuje da se sok od nara i sok od nara sa šećerom čuvaju u posudama napravljenim od legure SS 316L, koja je primenljiva i na vodovodni sistem.

***Ključne reči**: otpornost na koroziju, sok od nara, SS 304, legura SS 316L, elektrohemijska studija, AC impedansni spektri*

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