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Electrochemical impedance spectral study on the corrosion resistance of orthodontic wire made of Ni-Ti alloy immersed is artificial saliva in the presence of beer an alcoholic drink

ABSTRACT

To regulate tooth alignment, dentists use orthodontic wires made of materials such as SS 316L and Ni-Cr alloys. These wires are exposed to corrosive environments within the oral cavity, including artificial saliva, food items, beverages, and orally administered medications. This study investigates the corrosion resistance of Ni-Ti alloy in artificial saliva (AS), both in the absence and presence of beer—an alcoholic beverage produced by yeast fermentation of malt and flavored with hops—using polarization techniques. The results indicate that the corrosion resistance of the Ni-Ti alloy improves in the presence of beer. This is evidenced by an increase in charge transfer resistance, impedance, and phase angle, along with a decrease in double-layer capacitance when the alloy is immersed in AS containing beer. These effects are attributed to specific ingredients present in beer. The findings suggest that individuals using orthodontic wires made of Ni-Ti alloy can consume beer without concern for corrosion-related degradation of the material. Surface morphology was examined using scanning electron microscopy (SEM) and contact angle measurements.

Keywords: *Corrosion resistance, orthodontic wire, Ni-Ti alloy, artificial saliva, beer, EIS, SEM, contact angle, hydrophobicity*

1. INTRODUCTION

It is interesting to note that for some people the arrangement of teeth are in a regular manner by God's greatness. For some people it is not so. To regulate the growth of teeth Dentists make use of orthodontic wire made of various types of alloys such as SS 18/8, Ni-Cr, SS 316, Thermoactive super elastic alloy, Gold 18 K, Gold 20 K etc., After having clipped with orthodontic wires people take many food items, tablets, juice etc., orally. Apart from saliva, these food items, may corrode the orthodontic wires. Therefore a study on this aspect is necessary, to know how far these wires are affected and corroded. Many research papers have been available in this regard [1-10]. The present work is undertaken to investigate the corrosion behavior of orthodontic wire made of Ni-Ti alloy in artificial saliva when beer is taken orally. Electrochemical Impedance spectroscopy (EIS) has been employed for this purpose.

Influence of dilution and addition of soda water on the corrosion resistance of orthodontic wires immersed in artificial saliva in presence of Copper Barrel, a hard drink has been investigated by Hebciba Mary et al.[1]. Corrosion resistance of orthodontic wires made of Ni-Ti alloy and Ni-Cr alloy in artificial saliva in the absence and presence of copper barrel, water and soda water has been evaluated by AC impedance spectra. The study reveals that the people who have been clipped with orthodontic wire made of Ni-Ti alloy can take copper barrel in any form, namely, with dilution or without dilution. The people who have been clipped with orthodontic wire made of Ni-Cr alloy should avoid taking copper barrel in any form, namely, with dilution or without dilution [1].

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Niaz et al. have studied the effects of different mediums on the surface topography and corrosion of dental implant abutment [2]. The main objective of this study is **to** compare the effect of artificial saliva, carbonic drink and gutka extracts on the surface topography, corrosion kinetics and hardness of dental implant abutment. The investigation revealed thatchanges in surface topography and level of corrosion in dental implant abutments were found significant. Gutka extracts showed highest level of degradation and dissolution among all the mediums [2].

The effect of green tea in artificial saliva on the corrosion resistance behaviour of stainless steel, has been studied by Devimeenakshi et al.[3].The present survey shows that the persons cut with stainless steel orthodontic wire may drink oral green tea without concern. This is supported by Polarization study and alternating current impedance spectra and Atomic force microscopic technique [3].

Liu et al.[4] have conducted an investigation into the passive properties of TA10 in Coca-Cola containing oral environment. The corrosion resistance, composition of the passive film of TA10 alloy in different concentrations of Cola has been evaluated by polarization study and AC impedance spectra. It was observed that with the increase of cola content, the self-corrosion current density of the alloy increases sharply. The thickness of the passive film in AS, AS +cola and cola is about 9.5 nm, 7.5 nm and 6 nm, respectively. The passive film in cola has more defects and the carrier density is 1.55 times as high as that in AS. These results have important guiding significance for the safe use of the alloy in the complex oral environments [4].

A comparative electrochemical and morphological investigation on the behavior of NiCr and CoCr dental alloys at various temperatures,has been undertaken by Golgovici et al.[5].

The purpose of this investigation is to compare the behavior of two reprocessed dental alloys (NiCr and CoCr) at different temperatures considering the idea that food and drinks in the oral cavity create various compositions at different pH levels; the novelty is the investigation of temperature effect on corrosion parameters and ion release of dental alloys. Electrochemical stability was studied together with morphology, elemental composition and ions release determination. The results evidence that in accordance with increasing temperature, the quantities of ions released from the alloys immersed in artificial saliva also increase, though they still remain small, less than 20 ppm [5].

Nasir et al.[6] have inquired into the effect of packaged coffee drinks consumption to corrosion rate of stainless steel orthodontic wire. The objective of this study is to determine the effect of packaged coffee drinks consumption to corrosion rate of stainless steel orthodontic wire. Polarization study was used in this study. Luwak and robusta packaged coffee group had lower corrosion rate value than the control group. While Arabica packaged coffee group had higher corrosion rate value than the control group. Arabica packaged coffee drinks had the biggest effect on corrosion rate of stainless steel orthodontic wire [6].

Nasir and Amelia [7] have explored the effect of packaged tea drinks consumption to corrosion rate of stainless steel orthodontic wire. The objective of this investigate to determine the effect of packaged tea drinks consumption to corrosion rate of stainless steel orthodontic wire. Measurement of corrosion rate was done by using potensiostat tool and data analysis using SPSS version 23 and ANOVA test with significant value of $p<0.05$. Results showed that Jasmine and fruit flavor packaged tea group had lower corrosion rate value than the control group. While green packaged tea group had higher corrosion rate value than the control group. It is concluded that Green packaged tea drinks had the biggest effect on corrosion rate of stainless steel orthodontic wire [7].

Joany et al.[8] have conduct an investigation into Corrosion resistance of orthodontic wires in artificial saliva with presence of fragrant drink additives. Drinks may contain aroma compounds, which are also known as an odorant, aroma, fragrance, or flavor. Besides, aroma compounds have been used as corrosion inhibitors. People having irregular growth of teeth get clipped with orthodontic wires made of various alloys, such as SS316L and SS18-8 alloys. These alloys are in contact with saliva in the oral environment. Hence, these wires may undergo corrosion. Further the drink items we take orally such as juices flavored with aroma compounds may influence the corrosion rate of the orthodontic wires. Corrosion behavior at the nanoscale of SS18-8 alloy in artificial saliva with or without the presence of five aroma compounds (viz., vanilla, orange, lemon, pineapple, and rose) has been investigated by polarization study and AC impedance spectra. The hydrophobicity of the surfaces has been analyzed by contact angle measurement. In addition, the surface morphology of the protective film has been analyzed by AFM. The corrosion protection efficiencies of various systems are as follows:

vanilla>orange>lemon>pineapple>rose.

All these systems offer better corrosion protection to orthodontic wire made of SS18-8 alloy in artificial saliva. Hence, it is implied that people clipped with orthodontic wire made of SS18-8 alloy need not hesitate to take orally food items flavored with the investigated fragrant [8].

Nanjundan et al. [9] have inquired into evaluation of frictional resistance and surface characteristics after immersion of orthodontic brackets and wire in different chemical solutions. The aim of the study is to evaluate the changes of static and kinetic frictional forces between the brackets and wires following exposure to a soft drink, acidic food ingredient, and acidulated fluoride prophylactic agents. The findings may have long-term implications when acidic food substances are used during fixed orthodontic treatment. Further, in vivo studies are required to analyze the clinical effect of acidic mediums in the oral environment during orthodontic treatment [9].

Sangeetha et al.[10] have explored Corrosion resistance of SS 316 L alloy in artificial saliva in the presence of a soft drink. Corrosion resistance of orthodontic wires made of SS 316 L alloy in artificial saliva in the absence and presence of a soft drink namely sprite has been evaluated by polarisation study, when corrosion resistance increases, the linear polarisation resistance value increases and the corrosion current value decreases, the present study reveals that; the corrosion resistance of SS 316 L alloy decreases in the following order; sprite only > sprite + Artificial saliva > Artificial saliva. It is concluded that people who have been implanted with orthodontic wires made of SS 316 L alloy need not dither to take the soft drink sprite orally [10].

The present work is undertaken to investigate the corrosion behavior of orthodontic wire made of Ni-Ti alloy in artificial saliva when beer an alcoholic drink is taken orally. Electrochemical Impedance spectroscopy (EIS) has been employed for this purpose. That s it is to test if the orthodonitic wire made of Ni-Ti alloy undergoes corrosion, when beer is taken orally.

2. EXPERIMENTAL

Beer

Beer is one of the oldest types of alcoholic drinks in the world, and the most widely consumed. It is the third most popular drink. The meaning of BEER is a carbonated, fermented alcoholic beverage that is usually made from malted cereal grain (especially barley), is flavored with hops etc.

Ni-Ti alloy

Nickel–titanium (NiTi) (Nitinol) archwires are used in dentistry for orthodontic treatment. NiTi alloys have favourable mechanical characteristics, such as superelasticity and shape memory, and are also known as a corrosion-resistant alloy.

Preparation of the Nickel–titanium (NiTi) (Nitinol) specimens

The orthodontic wire was encapsulated in Teflon rod. It was polished to mirror finish and used for electrochemical studies.

Preparation of artificial saliva

The preparation of artificial saliva was done using the composition of Fusayama Meyer artificial saliva (AS). Artificial saliva was prepared in laboratory and the composition of artificial saliva was as follows: KCl - 0.4 g/lit, NaCl - 0.4 g/lit, $CaCl_2.2H_2O$ - 0.906 g/lit, $NaH_2PO_4.2H_2O$ - 0.690 g/lit, $Na_2S.9H_2O$ - 0.005 g/lit, urea – 1 g/lit.

AC Impedance spectra

In the present investigation a CHI 660 A workstation model was used to record AC impedance spectra , using a three electrodes cell assembly (Figure 1). Ni-Ti alloy was used as working electrode, platinum as counter electrode and saturated calomel electrode (SCE) as reference electrode.

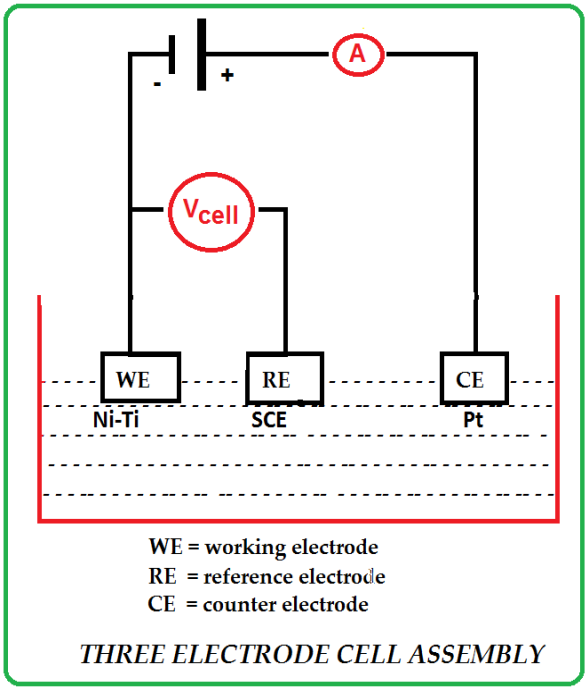

Figure 1. Three electrode cell assembly

A time interval of 5 to 10 min was given for the system to attain a steady state open circuit potential. The real part (Z') and imaginary part (-Z'') of the cell impedance were measured in ohms at various frequencies. AC impedance spectra were recorded with initial E (v) = 0, high frequency (Hz = $1x10^5$), low frequency (Hz = 1), amplitude (V) =

0.005 and quiet time (s) = 2. From Nyquist plot the Values of charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated.

$$R_t = (R_s + R_t) - R_s$$

Where

R_s = solution resistance.

C_{dl} values were calculated using the relationship

$$C_{dl} = 1/2 \times 3.14 \times R_t \times f_{max}$$

Where f_{max} = frequency at maximum imaginary impedance.

When corrosion resistance increases, R_t values, phase angle values and impedance values increase whereas C_{dl} values decrease (Figure 2).

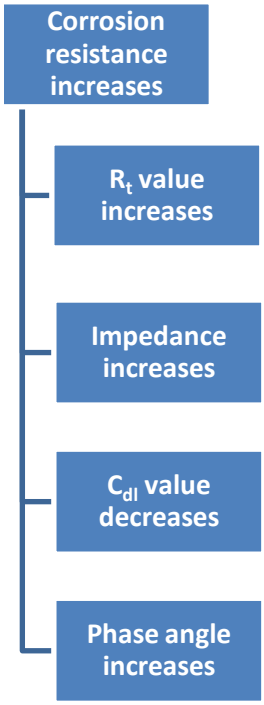

Figure 2. Correlation among corrosion parameters in AC impedance spectra

Analysis of AC impedance spectra

Electrochemical studies such as AC impedance spectra have been widely used in corrosion inhibition studies [11-15].

The AC impedance spectra of Ni-Ti alloy immersed in various test solutions are shown in Figures 3-10.

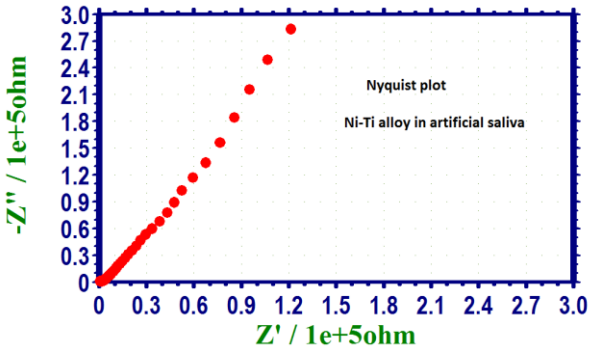

Figure 3. Nyquist plot of Ni-Ti alloy immersed in artificial saliva(AS)

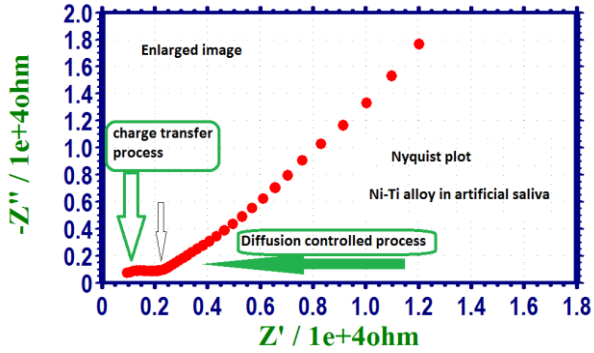

Figure 4.Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS) (Enlarged image)

The corrosion parameters are compared in Figures 11 and 12. The equivalent circuit diagrams for the two Nyquist plots is (charge transfer process and diffusion controlled process) shown in Figure 13.

The corrosion parameters are given in Table 1. Bearing in mind that in AC impedance spectral analysis, when corrosion resistance increases, charge transfer resistance increases, impedance value increases, phase angle increases and double layer capacitance decreases (Figure 10), it is inferred that in the presence of BEER, the corrosion resistance of orthodontic wire made of NiTi alloy increases[11-15]. This is due to the ingredients present in the beer.

Implication

People clipped with orthodontic wire made of NiTi alloy need not hesitate to take beer orally.

Table 1. Corrosion parameters of Ni-Ti alloy immersed in artificial saliva (AS) in the absence and presence of BEER obtained AC impedance spectra

System	Rt Ohmcm^2	impedance log(Z/ohm)	Phase angle	Cdl F/cm2
AS	11724	5.527	37	43.50 x10-11
AS + BEER	257784	5.677	53	1.988 x10-11

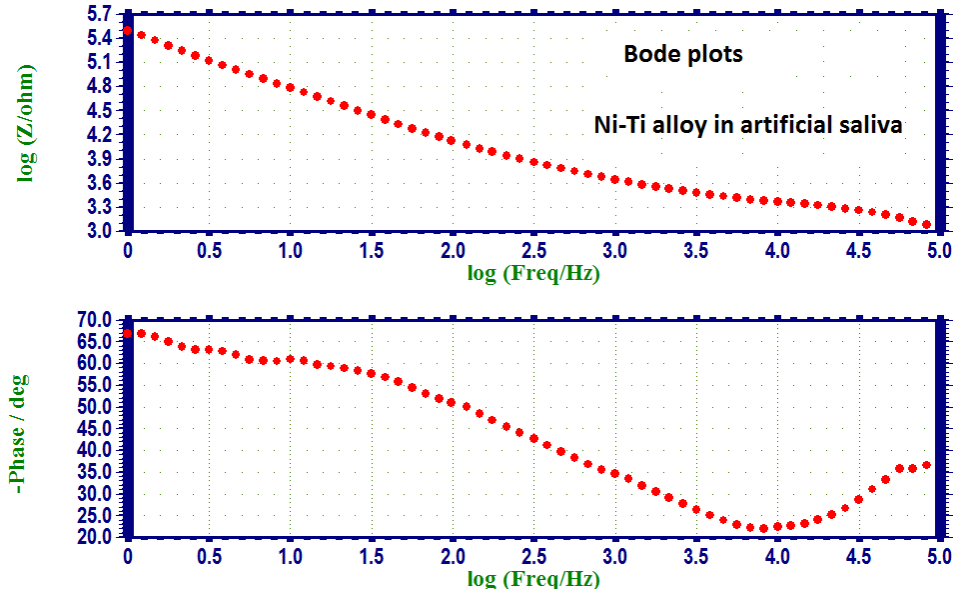

Figure 5.Bode plots of Ni-Ti alloy immersed in artificial saliva (AS)

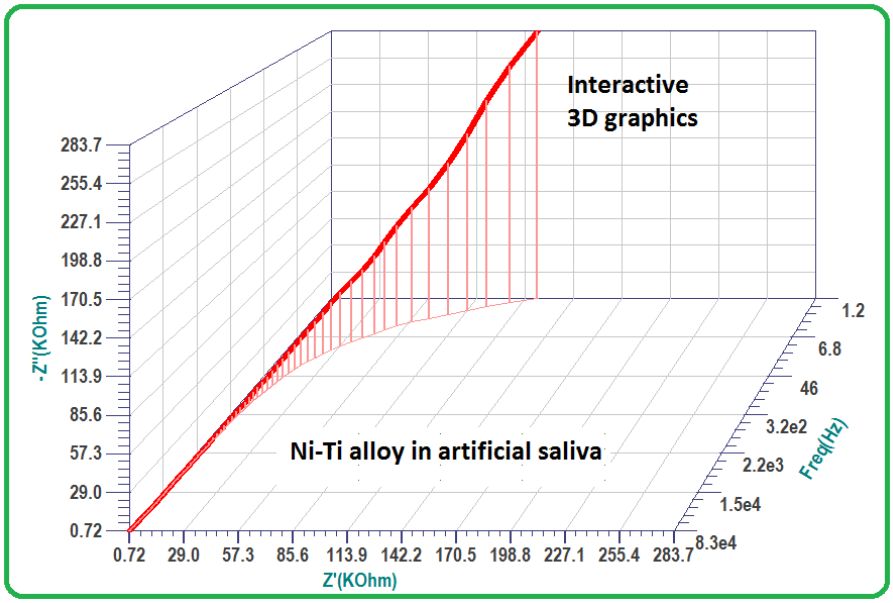

Figure 6. Interactive 3D graphics of Ni-Ti alloy immersed in artificial saliva (AS)

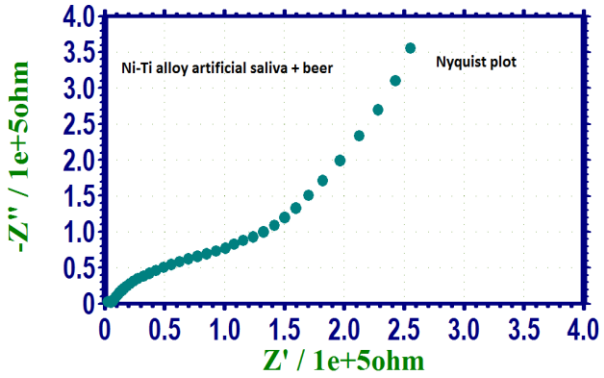

Figure 7.Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS) + beer

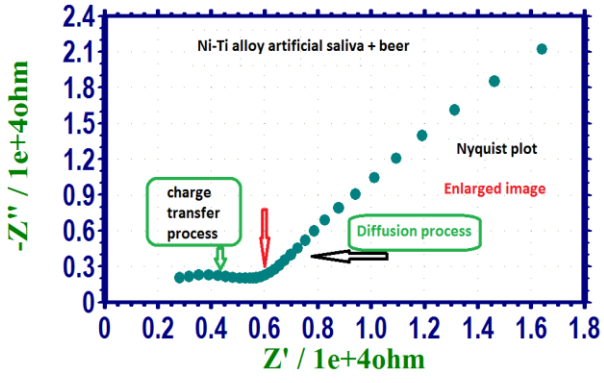

Figure 8.Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS) + beer (Enlarged)

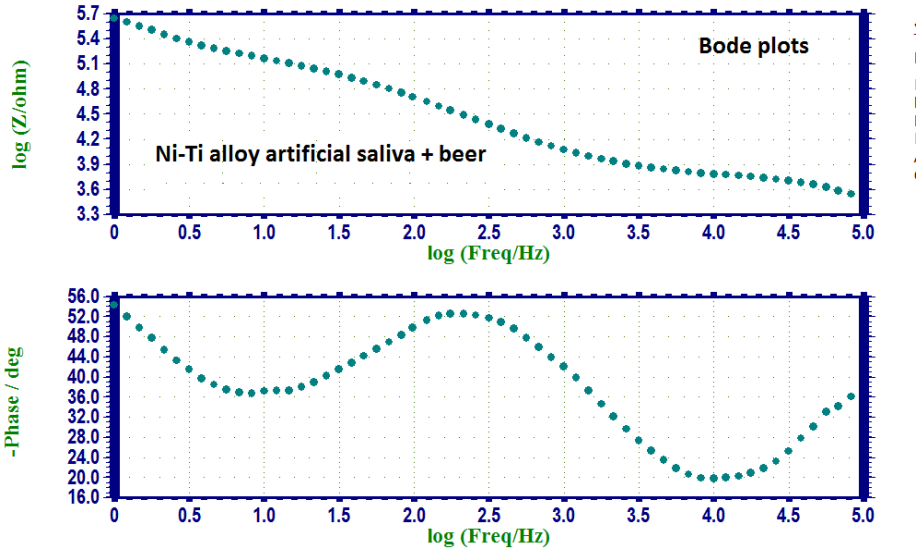

Figure 9. Bode plots of Ni-Ti alloy immersed in artificial saliva (AS) + beer

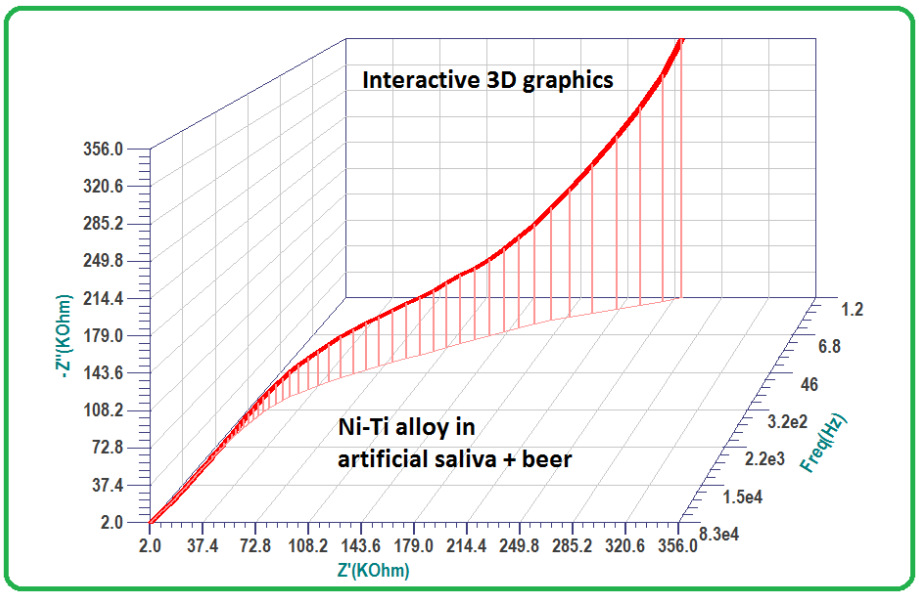

Figure 10. Interactive 3D graphics of Ni-Ti alloy immersed in artificial saliva (AS) + beer

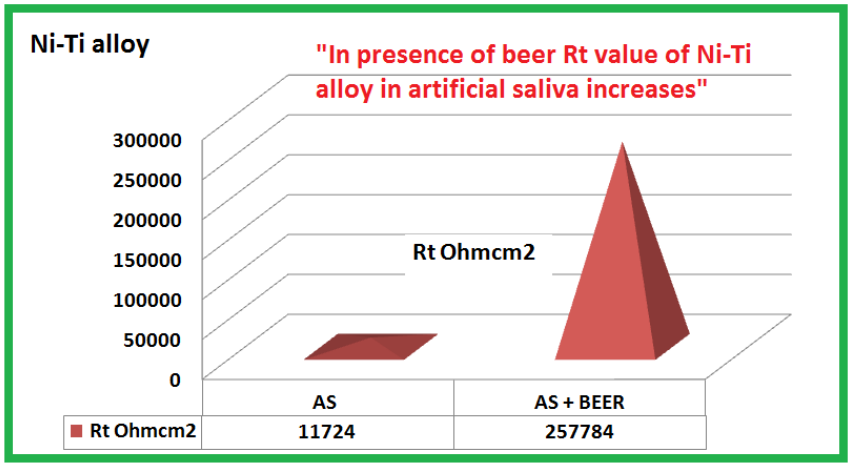

Figure 11. Comparison of Rt values

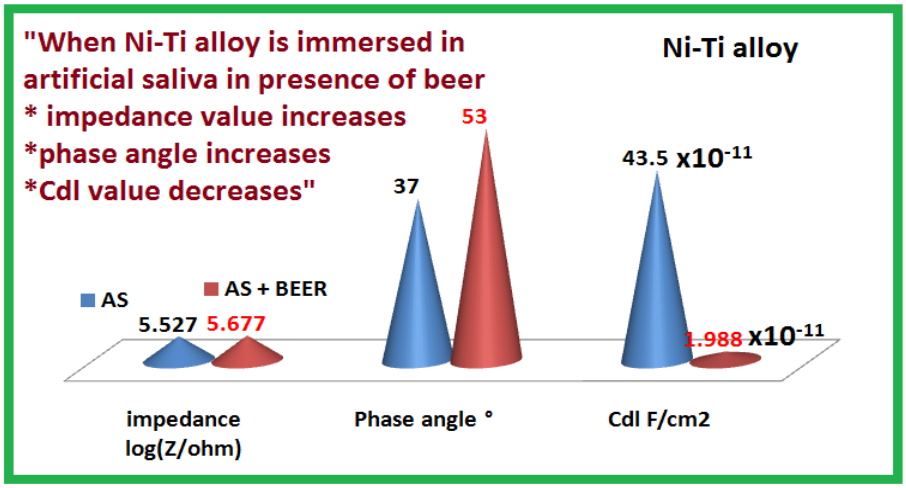

Figure 12. Comparison of impedance values, phase angles and double layer capacitance values

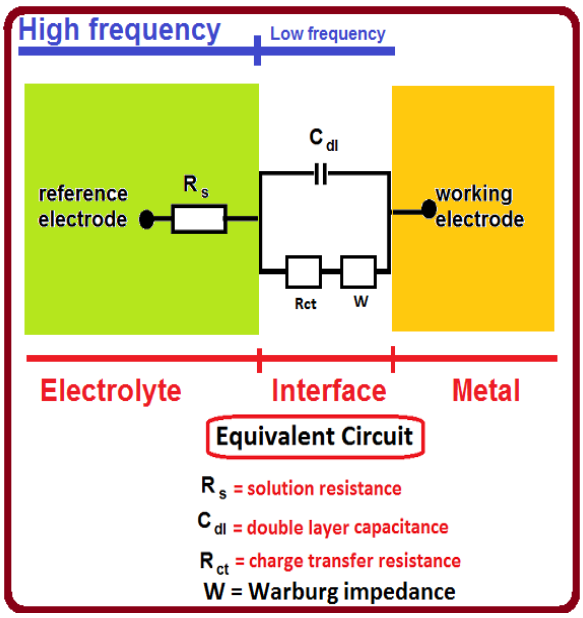

Figure 13. Equivalent circuit for kinetic and diffusion processes

SEM images analysis

SEM images analysis has been used in corrosion inhibition studies [16-20]. For corroded surfaces the SEM image is roughness and pits will be noticed. For corrosion protected surface the image will be smooth. The pits will be less, depending on the degree of protection. SEM images of various surfaces are shown in Figure . It is observed that when Ni-Ti alloy is immersed in artificial saliva some pits are noticed on the metal surface. On the other hand when Ni-Ti alloy is immersed in artificial saliva in the presence of beer the surface becomes smooth. That is there is corrosion protection on the metal surface. This is supported by results of the AC impedance spectra (Table 1). There is increase in charge transfer resistance; increase in impedance value; increase in phase angle value and decrease in double layer capacitance value.

Implication

People clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take beer orally.

Figure 14.SEM images of various metal surfaces

Contact angle measurement

Contact angle measurement has been used in corrosion inhibition studies [21-25]. When the metal corrodes, the contact angle decreases. The wettability increases. Hydrophilic nature increases. When the metal is protected from corrosion, the contact angle increases. The wettability decreases. Hydrophilic nature decreases. Hydrophobicity increases (Figure 15, Table2). When Ni-Ti alloy is immersed in artificial saliva in presence of beer, the contact angle increases from 57.2° 97.3°.That is when Ni-Ti alloy is immersed in artificial saliva in the presence of beer, the corrosion resistance of Ni-Ti alloy increases (Figure 16). This is also supported by the results of the AC impedance spectra.

Implication

People clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take beer orally.

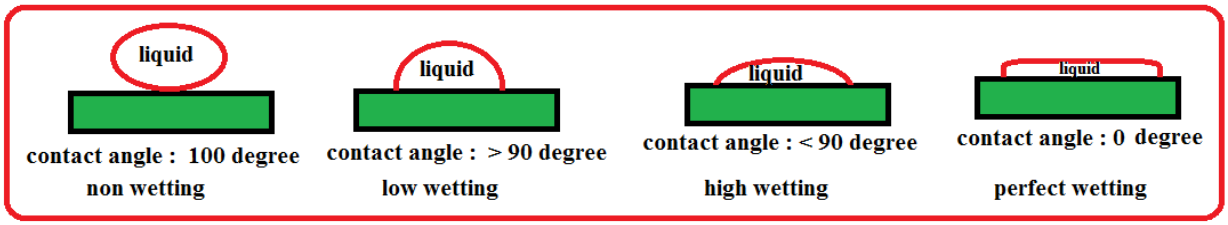

Figure 15. Contact angle and wetting

The following Table2 explains the relation between contact angle and hydrophobicity.

Table 2. Contact angle and hydrophobicity

Contact angle Ø	Nature	Surface energy	Effect
< 90°	Hydrophilic	Increases	water droplets spread out
>90°	Hydrophobic	Decreases	water droplets beads-up
90° to 120°	Hydrophobic	Decreases	water droplets beads-up
>150°	Super- Hydrophobic	Decreases	water droplets bead highly (Repelled)

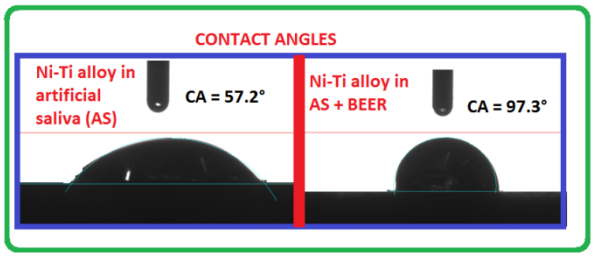

Figure 16. Contact angles of various surfaces

CONCLUSION

- Corrosion resistance of Ni-Ti alloy in artificial saliva (AS) , in the absence and presence of beer, an alcoholic drink made from yeast-fermented malt flavoured with hops, has been investigated by polarization study.
- It is inferred that corrosion resistance of Ni-Ti alloy in artificial saliva increases in the presence of beer.
- This is revealed by the facts that when Ni-Ti alloy is immersed in artificial saliva in the presence of beer charge transfer resistance increases, impedance value increases, phase angle increases and double layer capacitance decreases.
- This is due to the ingredients present in the beer.
- It implies that people clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take beer orally.

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IZVOD

SPEKTRALNA STUDIJA ELEKTROHEMIJSKE IMPEDANCE OTPORNOSTI NA KOROZIJU ORTODONTSKE ŽICE OD LEGURE Ni-Ti URONJENA JE VEŠTAČKA PLJUVAČKA U PRISUSTVU PIVA I ALKOHOLNOG PIĆA

Da bi regulisali rast zuba, stomatolozi koriste ortodontske žice kao što su SS 316 L, Ni-Cr itd., Ove žice podležu koroziji u okruženju pljuvačke. Osim toga, oni su podvrgnuti koroziji od hrane, sokova i tableta koje ljudi uzimaju oralno. Otpornost na koroziju legure Ni-Ti u veštačkoj pljuvački (AS), u odsustvu i prisustvu piva , alkoholnog pića od slada fermentisanog kvascem aromatizovanog hmeljem, ispitana je polarizacionom studijom. Zaključuje se da se otpornost legure Ni -Ti na koroziju u veštačkoj pljuvački povećava u prisustvu piva . Ovo otkriva činjenica da kada se legura Ni-Ti uroni u veštačku pljuvačku u prisustvu piva, otpor prenosa naelektrisanja raste, vrednost impedanse raste, fazni ugao raste i kapacitivnost dvostrukog sloja opada. To je zbog sastojaka prisutnih u pivu. To implicira da ljudi ošišani ortodontskom žicom od legure Ni-Ti ne moraju oklevati da piju pivo oralno. Morfologija površine je procenjena SEM i merenjem kontaktnog ugla.
Ključne reči: *Otpornost na koroziju, ortodontska žica, Ni-Ti legura, veštačka pljuvačka, pivo, EIS, SEM, kontaktni ugao, hidrofobnost*

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