Comparative kinetics of corrosion rate on mild steel in various citrus juices

Nabeel Ahmad, Mohammad Imran Husain, Rohit Kumar, Saikat Mukherjee and Rajiv Dutta*
School of Biotechnology, IFTM University, NH-24 Delhi Road, Lodhipur Rajput, Moradabad, U.P.- 244102 India. (*Corresponding author: director.sbt@gmail.com)

Abstract: This research aims to compare the corrosion effects on mild steel of various citrus juices. Here we used weight loss of mild steel test alloy specimens in the presence of various citrus juices as an indicator of corrosion. The kinetics of corrosion in the mild steel alloy was found to be significantly different when immersed in different citrus juices and the rate of corrosion was found to be maximum in grape juice (11.53 Mp×10^{-3}) followed by lemon (7.96 Mp×10^{-3}), pine-apple (7.05 Mp×10^{-3}) and orange juices (6.85 Mp×10^{-3}) respectively.

Keywords: Corrosion Rate Kinetics; Weight Loss; Mild Steel Alloy; Citrus Juices

I. INTRODUCTION

Corrosion is a type of reaction of material with the environment. We can say that probably destruction of a function or system. The word corrosion comes from the Latin word “corrodere”, which means to gnaw away. It usually begins at the surface of a material and occurs because of the spontaneous tendency of the materials to return to their thermodynamic stable state or to one of the forms in which they were originally found. Such effects are some time important in the food processing as well in the bioprocessing industry. Steel materials are widely used to maintain the oxygen transfer rate, mass transfer coefficient, driving force inside the bioreactor. Steel materials are also used for packing, or different aspects of food packaging and processing industry (Ashassi-Sorkhabi, 2009). Mild steel material used for equipment manufacturing purposes because it had good mechanical property like of its strength, ductility, and weldability (Bolton, 1994; Smith and Hashemi, 2006). Mild steel corrodes easily because all common structural metals like C, Mn, P, S, Si, Fe element form surface oxide films when exposed to pure air but the oxide formed on mild steel is readily broken down, and in the premoisture, it is not repaired (Table 1). Therefore, a reaction between steel (Fe), moisture (H_2O) and oxygen (O_2), takes place to form rust (Janaina et al, 2010). This reaction can be represented by a chemical equation of the following type:

4Fe+2H_2O+3O_2→2Fe_2O_3H_2O

2Fe_2O_3H_2O is a type of rusting material and it is not usually protective; therefore, the corrosion process is not impeded.

Aluminum, tin and its alloys plate containers for packaging of liquid foods (various kind of preservative juices or cold drinks, alcoholic beverages) is due to most of its advantages; they include ease of packing and sterilizing, transporting and minimizing the loss of nutritive value and maintain the food stuff because of the anaerobic environment of the sealed can. These containers are made with plain carbon steel plates with a thin coating of tin (American Can Company, 1973). In an empty tin can, the tin plate is cathodic and the steel base is anodic. This is kept from the corrosion-susceptible mild steel base by the corrosion resistant tin layer. If a corrosive acidic liquid is present, a reversal of polarity takes place. Tin now becomes the local anode and steel base the local cathode. Thus, the protective mode of the tin plate is now via an electrochemical process and this happens in canned acidic fruit juices such as citrus juices (Jimenez and Kane, 1974). Mild steel as constructional materials are often exposed to juice or used to package juice to a great extent during service. This exposure can be under conditions of varying temperature, flow rate, pH and other factors; all of which can alter the rate of corrosion (Eddy and Ebenso, 2008). The relative acidity of the solution is the most important factor to be considered; at low pH, the evolution of hydrogen tends to eliminate the possibility of protective film formation so that steel continues to corrode but in alkaline solutions, the formation of protective film greatly reduces corrosion rate (Badmos and Ajimotokan, 2009). In this research we examined the corrosion rate and weight loss of mild steel in various citrus juices in order to find its utility towards food industry as well as in bioprocess industry.
II. MATERIALS AND METHODS

A. Specimen Preparation

The specimen used for detection of corrosion is mild steel alloy. Total nine specimens were prepared at the workshop in the Department of Mechanical Engineering of School of Engineering at the I.F.T.M. University Moradabad INDIA. The specimens were cut in to size of 4.4×2.2 cm with thickness of 0.5 cm and perforated at the centre in order to allow the passage of the thread through the hole. The surface of the specimens were cleaned and prepared by using different grades of emery paper (100,120,200,400), ethanol (70%), distilled water, respectively and were allowed to air dry in an oven at 25°C.

B. Juice Preparation

Natural fruits and preservative Juices (Orange, Pineapple, Lemon, Grapes) were purchased from local market. Natural fruits were procured using kitchen juicer. Natural juices were then filtered out to make it fiber free and were collected into 100 ml flasks and beakers and pH of each juices were measured carefully.

C. Procedure

These experiments were carried out in the Microbiology Lab of School of Biotechnology of I.F.T.M. University Moradabad INDIA to avoid any microbial contamination. Each weighed specimen was suspended with aid of thread in separately erlenmeyer flask. The reason could be due to preservatives itself causing corruptions (Gardner and Nathan, 2000). On the other hand the distilled water is found to be having minimum corrosion effect on steel when compared to other juices. The weight loss is found to be having an exponential phase within a short time interval followed by a saturation. The phenomenon is similar for all the different juices. When it is compared the corrosion rate of the different juices as shown in Figure 2 grape juice is found to be having highest corrosion rate followed by lemon, pineapple and orange juice. The corrosion rate is found to be maximum initially within a few days time interval and gradually getting decreased till it attained saturation (Table 2).

The corrosion was observed due to the oxidative reaction occurring initially at the surface of the metals and proceeding impedes. The oxidation occurs first at the surface of the metal and the resulting metal oxide scales forms a barrier, which tends to restrict further oxidation.

Metal+ Oxygen→ Metal Oxide (Corrosion Product)

All the gaseous molecules (O₂, CO₂) were absorbs rapidly by the surface of the metal as atom, ions, and containing either natural juices (Orange, Pineapple, Lemon, Grapes) or preservatives juices (Orange, Pineapple, Lemon, Grapes) and distilled water (control). The total exposure time was 20 days and measurements of weight loss of the specimens in various citrus juices were calculated at interval of two days. The average corrosion rates of the mild steel specimen in various environments were determined by empirical dependencies developed by Ovri and Ofek (1998), Fontana (1987), Osarolube et al. (2004) and Avwiri (2004), which was as follows:

\[ CR= \frac{534W}{A} \]

Where, CR is the corrosion rate in millimeter per year, W is the weight loss in mg, \( \rho \) is the metal density in mg/m³, A is area of specimen in m² and T is the exposure time in hours.

III. RESULT AND DISCUSSION

The data show all the different citrus acid juices have capability to corrode the steel, however with different kinetics of corrosion was different for each juices. The weight loss of the specimen at various time intervals when immersed in different juices is shown in figure 1. Weight loss is found to be maximum in grape juice followed by lemon, pineapple and orange juice respectively. For each case, corrosion effect is more in presence of preservatives when compared to the natural juice. molecules. This is followed by the diffusion of the gas in metal.

\[
\begin{align*}
Fe+O+2CO_2+H_2O & \rightarrow \text{Fe (HCO}_3\text{)}_2 \\
2Fe (\text{HCO}_3\text{)}_2+H_2O+O & \rightarrow 2Fe (\text{OH})_2+2CO_2+2H_2O \\
2Fe (\text{OH})_2+2H_2O & \rightarrow 2Fe (\text{OH})_3+2CO_2 
\end{align*}
\]

These equations implies, that rusting of specimens was due to the continuous action of the oxygen, carbon dioxide and moisture, converting the metal into a soluble ferrous bi carbonates which was further oxidized to basic ferric carbonate and finally ferric hydroxide which gets converted to hydrated ferric oxide i.e. the rust. Corrosion is due to formation of the rust. The differences in kinetics of corrosion of steel in different juices were probably due to the difference in pH of the various juices.

IV. CONCLUSION

In food packaging industry requires protection tempering resistance and special physical chemical or biological means. Certain measures should be followed regarding food packaging and processing industry in order to avoid potentially severe health hazard. Many fruit processing industry uses processing units made up of steel because of easier processing better maneuverability, handling and easier heat transfer requirement. If the grade of stainless
steel is correctly specified for the application, corrosion should not be encountered. Different type of corrosion can also be formed in steel. Surface finish and condition is very important to the successful application of stainless steels. Smooth surfaces not only promote good cleansibility but also reduce the risk of corrosion. This research shows that containers, made up of mild steels are not a good processing or storage material for preservation of various drinking products like various juices as the corrosion products in forms of metallic oxide could be hazardous to the health. It would be interesting to look corrosion effect of various citrus juices on other metal alloy and to compare the corrosion rate to choose for optimum metal alloy for packaging and processing industry.

REFERENCES


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Figure 1: Comparison of weight loss of mild steel alloy in various citrus juices like Orange juice with preservative (Orange P), Orange juice without preservative (orange N), Lemon juice with preservative (Lemon P), Lemon juice without preservative (Lemon N), Pineapple juice with preservative (Pine apple P), Pineapple juice without preservative (Pine apple N), Grape Juice with preservative (Grape P), Grape Juice without preservative (Grape N) and distilled water.
Figure 2: Corrosion rate kinetics of mild steel alloy in various citrus juices like Orange juice with preservative (O.P), Orange juice without preservative (O.N), Lemon juice with preservative (L.P), Lemon juice without preservative (L.N), pineapple juice with preservative (P.P), pineapple juice without preservative (P.N), Grape Juice with preservative (G.P), Grape Juice without preservative (G.N).
Table 1: Chemical Composition of the mild steel alloy

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<th>Element</th>
<th>Fe</th>
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<th>C</th>
<th>S</th>
<th>Si</th>
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<td>Weight in %</td>
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<td>0.15</td>
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Table 2: Tabulation of Corrosion rate of mild steel alloy at various exposure time in different citrus juices like Orange juice with preservative (O. P), Orange juice without preservative (O.N), Lemon juice with preservative (L.P), Lemon juice without preservative (L.N), pineapple juice with preservative (P.P), pineapple juice without preservative (P.N), Grape Juice with preservative (G.P), Grape Juice without preservative (G.N)

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Nabeel Ahmad is as an Assistant Professor in School of Biotechnology at IFTM University Moradabad U.P. India. He has completed his M.Tech in Biotechnology from Integral University Lucknow in 2009 following his B.Tech in Biotechnology from College of Engineering & Technology, Moradabad in 2007. Currently, pursuing his Ph.D degree in Molecular Nano-Biotechnology and his area of interest are Nanobiotechnology, Process Engineering and Bioreactor Designing, Modeling and Simulation for biomedical engineering.

Mohammad Imran Husain is final year of undergraduate degree at the School of Biotechnology, IFTM University Moradabad. His areas of interest are biomedical engineering and genetic engineering.

Rohit Kumar pursuing is final year of undergraduate degree at the School of Biotechnology, IFTM University Moradabad. His areas of interest are microbiology and genetic engineering.

Dr. Saikat Mukherjee is an Assistant Professor in IFTM University, Moradabad. He has done his PhD from Indian Institute of Chemical Biology, Kolkata, India and post doctoral research in Department of Molecular Biology, University of Geneva. He is an alumni member of International Human Frontier Science Foundation, European Curie Science Commission and Noble Laureates meeting community network, Lindau, Germany. His area of interest are mitochondrial and chloroplast biochemistry and proteomics.

Dr. Rajiv Dutta is Director, School of Biotechnology and Professor in Biotechnology & Bioengineering at IFTM University, Moradabad, India. He earned M.Tech. in Biotechnology and Engineering from the Department of Chemical Engineering, IIT, Kharagpur and Ph.D. in Biotechnology from BITS, Pilani. His area of research interest includes Biophysics, Electrophysiology, Membrane Nanopores and Bioengineering Earlier to this assignement he was Faculty at BITS, Pilani; Department of Botany at Oklahoma State University, Stillwater, USA; Department of Biological Sciences at Purdue University, West Lafayette, USA and Amity Institute of Biotechnology, Amity University Uttar Pradesh, Lucknow. He is Fellow of American Academy of Science & Technology. He had received various awards including JCI Outstanding Ten Young Person of India 1998 and ISBEM Dr. Ramesh Gulrajani Memorial Award 2006 for outstanding research in electrophysiology.