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Full Length Research Paper

Investigation of corrosion effect of mild steel on orange juice

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This paper aims to investigate the corrosion effect of mild steel in orange juice using a weight loss technique. Test specimens with known weights were immersed in the test media (orange juice with preservatives, natural orange juice and water) for a total exposure time of 10 days. Weight loss was measured at two day intervals for the determination of corrosion rate effect. Corrosion aggressive substance was discovered to have significant impact on the degradation of equipment and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions. Results revealed that the corrosiveness of sweet orange juice on mild steel was mainly a function of its acidity. Packed orange juice with preservative was most corrosive followed by natural orange juice and water, respectively.

Key words: Corrosion, mild steel, weight loss, orange juice, acidity.

INTRODUCTION

Corrosion of metals and their alloys when exposed to the action of acids in industrial processes are recognized as major contributions to infrastructure deterioration (Ovri and Ofeke, 1998). These effects are particularly important in the food processing industry. Food substances, like other organic and in-organic substances are increasingly becoming corrosive thereby, causing significant degradation of materials used for equipment and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions (Osarolube et al, 2004; Callister, 2008). These corrosive effects on different equipment or materials in different aspects of food processing and packaging are common (Ashassi-Sorkhabi, 2009)..

The material used for most equipments used in the manufacturing sector is mild steel; it is selected because of its strength, ductility and weldability (Bolton, 1994; Smith and Hashemi, 2006). Mild steel corrodes easily because all common structural metals form surface oxide films when exposed to pure air but the oxide formed on mild steel is readily broken down, and in the presence of moisture, it is not repaired. Therefore, a reaction between steel (Fe), moisture (H_2O) and oxygen (O_2), takes place to form rust (Janaina et al 2010). This reaction is complex but it can be represented by a chemical equation of the following type:

$$4Fe + 2H_20 + 3O_2 = 2Fe_2O_3.H_2O \quad (1)$$

$Fe_2O_3.H_2O$ is the rust, and it is not usually protective; therefore, the corrosion process is not impeded.

Extensive use of tin plate containers for packaging of liquid foods is due to most of its advantages; they include ease of packing and sterilizing, transporting and minimizing the loss of vitamin potency in 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

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Table 1. Chemical composition of the mild steel alloy.

Element	C	Mn	P	S	Si	Fe
Weight (%)	0.08	0.35	0.014	0.018	0.17	99.4

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).

Citrus species are utilized in many industries for the production of various brands of citrus juices and they are rich in vitamin C, folic acid and significant quantities of other vitamins, pectin, flavonoids. The principal acid in citrus fruits is citric acid (80 to 90% of the total acids). Others are malic, tartaric, benzoic, succinic, quinic, oxalic and formic acids. Nitrogenous compounds are present at the rate of 0.05 to 1.0%, mostly as free amino acids–asparagines, alanine, arginine, aspartic acids, glutathione, histidine, betaine, cysteine, praline, serine and stachydrine (Abiola et al., 2004).

During the preservation of canned citrus juices, an interaction occurs between the components of the canned food and the material of the can. Corrosion in canned acid products is often influenced by the chemical composition of the products, character of the tin plate and the presence of the corrosion accelerators such as sulfites, sulfurdioxide and oxygen. Studies of corrosion mechanism have shown that the process entails dissolution of the tin coating, dissolution of the steel base and evolution of hydrogen. One of the most practical methods is the use of inhibitors for protection against corrosion, prevention of unexpected metal dissolution and acid consumption, especially in acid solutions.

There are different organic and inorganic compounds that have been studied as inhibitors to protect metals from corrosive attacks. The efficiency of these organic corrosion inhibitors is related to the presence of polar functions with S, O or N atoms in the molecule, heterocyclic compounds and its electrons. These compounds can adsorb on the metal surface and the active surface site, thus reducing the corrosion rate. Most synthetic compounds show good anticorrosive activity; most of them is highly toxic to both human beings and the environment, and they are expensive and non-biodegradable (Satapathy et al, 2009; Rocha, 2010).

The use of natural products as corrosion inhibitors has become a key area of research interest because the extracts of their leaves, seeds, fruits roots and peels has been reported as effective corrosion inhibitors in different aggressive environments. Extracts of fruit peel (mango and orange) has been used as corrosion inhibitors against corrosion of mild steel, aluminum, zinc and copper in HCl and H_2SO_4 solutions (Ganesha et al, 2008; Badiea and Mohana,2009). The use of industrial waste as a corrosion inhibitor is quite interesting from the standpoint of economics and the environment. The use of aqueous extracts of fruits peels as inhibitors promotes the values of the juice industry; moreover, they are environmentally friendly.

This work examines the corrosion of mild steel in orange juice environments to provide a better understanding of the corrosiveness behavior of the orange fruit, thereby enhancing the material selection and effective surface treatments to increase corrosion resistance.

MATERIALS AND METHODS

The material used for this investigation is a mild steel alloy with a thickness of 0.1 cm, cut into specimen of sizes of 4 cm by length and 2.5 cm by width and perforated at the centre with holes to allow the passage of thread. The specimens were surface-prepared using different grade emery paper, ethanol and water; and then, dried. Natural orange juice was prepared and other media were procured; and the pH of each medium was measured. The chemical composition of the mild steel used for the experiment is listed in Table 1.

Each weighed specimen of the metal was suspended with the aid of a thread in the beakers each containing orange juice with preservatives, natural orange juice and water. The specimen exposure periods were a total of 10 days with six measurements taken at an interval of two days, respectively. The average corrosion rates of the specimen in various environments were determined using methods of Ovri and Ofeke (1998), Fontana (1987), Osarolube et al. (2004) and Avwiri (2004) as

$$CR = \frac{534\,W}{\rho A T} \tag{2}$$

Where, CR is the corrosion rate in millimeter per year, W is the weight loss in mg, ρ is the metal density in mg/m^3, A is area of specimen in m^2 and T is the exposure time in hours.

RESULTS AND DISCUSSION

Uniform corrosion was observed in almost all specimens immersed in the media as no pit or holidays were noticed. Figures 1 and 2 show the results of the variation of weight loss (g) as a function of exposure time (days) and the corresponding corrosion rate as a function of expo-

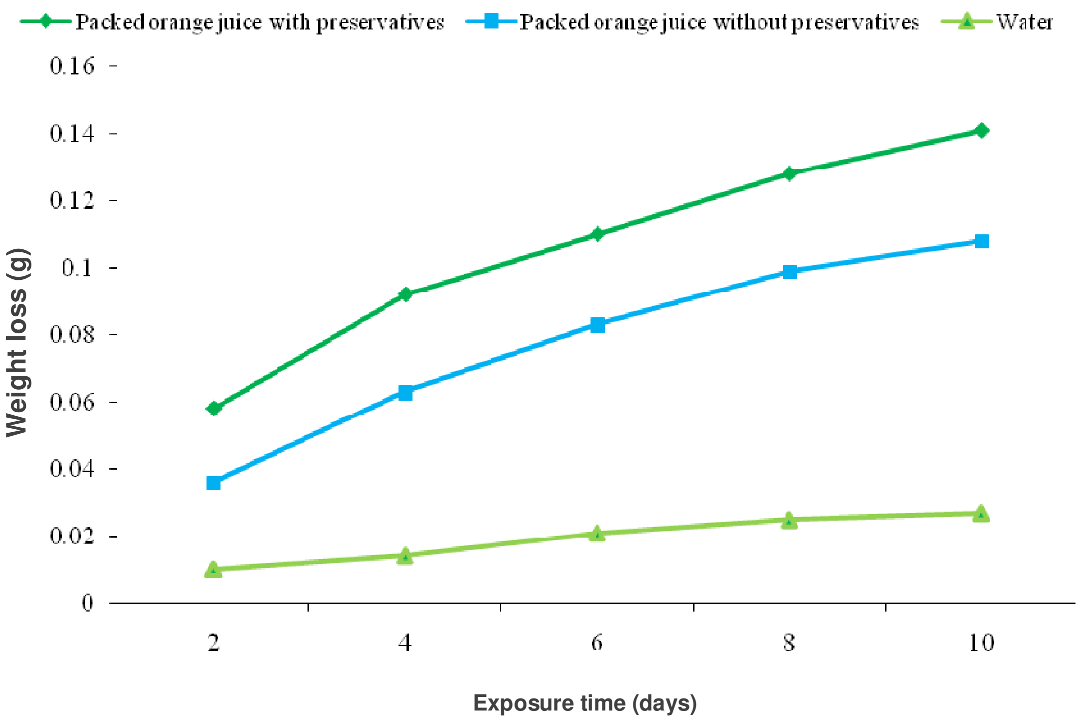

Figure 1. Variation of weight loss vs. exposure time for all media.

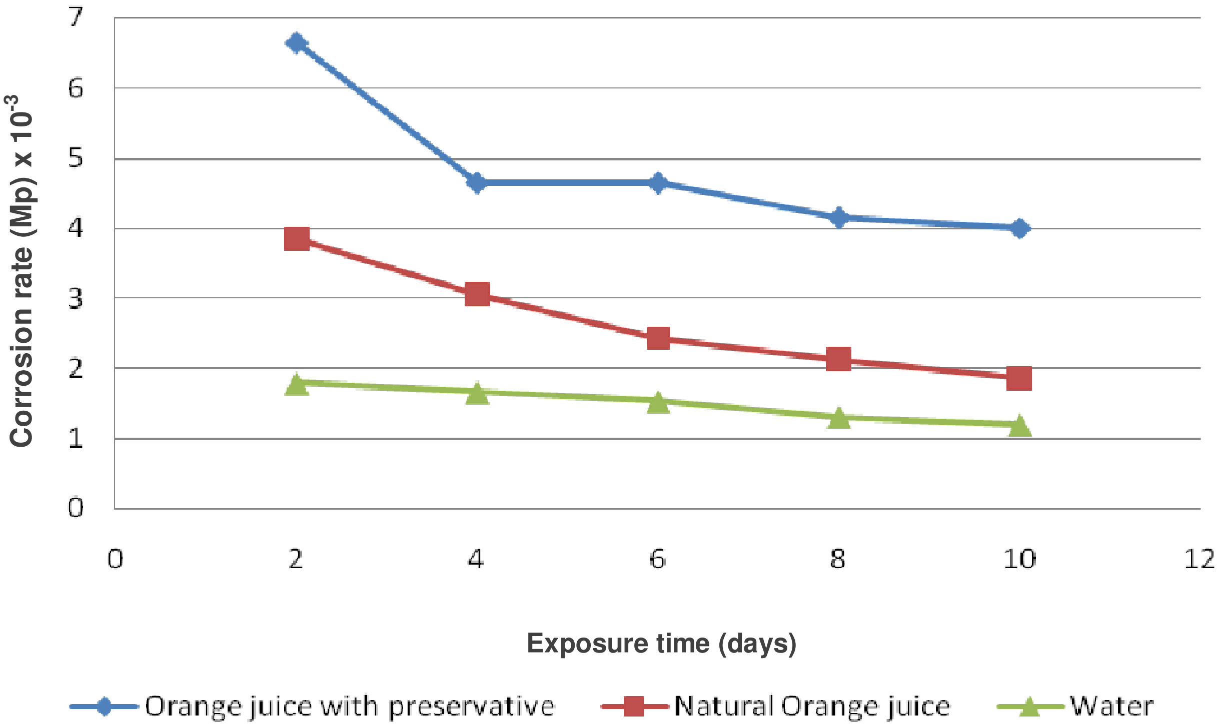

Figure 2. Variation of corrosion rate vs. exposure time for all media.

sure time (days) for all test media, respectively, while Table 2 shows the corrosion rates of mild steel in the test media. The result shows that weight loss of the specimen is highest in the orange juice with preservative followed by natural orange juice and the least weight loss was observed in water. Food additives increase the corro-

Table 2. Corrosion rate of mild steel in the test media.

Exposure time (days)	Orange juice with preservatives (mpy) x 10^{-3}	Natural orange juice (mpy) x 10^{-3}	Water (mpy) x 10^{-3}
2	6.65	3.85	1.79
4	4.65	3.06	1.66
6	4.65	2.44	1.53
8	4.15	2.13	1.31
10	4.00	1.87	1.20

siveness of steel (Figure 1) in an environment. Food additives as in the case of orange juice with preservatives, contribute to various corrosive properties of refined orange juice (Badmos and Ajimotokan, 2009).

Corrosion in the orange medium is very substantial because citric acid (80 and 90% of the total acids) is recognized as an oxidizing agent. An autocatalytic mechanism has generally been proposed to explain the high rates of corrosion in acids (Avwiri, 2004; Haleem et al., 1980) with primary displacement of H^+ ions from solution; followed by acid reduction rather than hydrogen evolution as acid reduction leads to a manifest decrease in free energy. This reaction is complex but it can be represented by a chemical equation of the following type:

$$Fe^{2+} + OH^{-} = Fe(OH)_2 \qquad (3)$$

Though a loose blue or green corrosion product suggestive of ferrous hydroxide {Fe $(OH)_2$} was observed, it readily turned red brown on removal and exposure to the atmosphere. This transformation was as a result of the oxidation of the ferrous hydroxide Fe $(OH)_2$, to ferric hydroxide Fe $(OH)_3$ as shown:

$$Fe(OH)_2 + O_2 = Fe(OH)_3 \qquad (4)$$

However, the mechanism of corrosion in water is comparatively simple; it is difficult to predict how corrosion will proceed in practice. The result shows that water was less corrosive to mild steel when compared with orange juice (Figures 1and 2).

There was a substantial rise in pH of all the test media except in water with the passage of time and passivity not notable. These are due to the various chemical reactions and other processes like fermentation, oxidation and corrosion products dissolution as there was increase in colouration of the media with increase in exposure time.

Conclusions

This research proved that mild steels are corrosive in fruit juice environments due to the evolution of hydrogen gas (a cathodic reaction product) at low pH resulting in the possibility of the elimination of protective formation of hydrogen (H_2). It was discovered that corrosion rate was highest in the orange juice with preservatives due to a combination of citric acid and the preservatives (food additives). Fruit juice demands a considerable degree of processing such as milling, pressing and concentration by evaporation, storage and packaging using metallic materials. Mild steel corrosiveness relatively make it undesirable economically and health-wise because these corrosion products may find their ways into the bulk of the juice causing off-taste, off-flavor and off-texture which may equally be hazardous to health.

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