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Full Length Research Paper

Electrochemical properties of metals in cassava fluid

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This study was carried out to investigate and evaluate the electrochemical properties of mild steel (0.6, 1.0 and 1.46 mm), galvanized steel (0.36, 0.6 and 1.24 mm) and aluminium (0.9 and 1.3 mm) sheets exposed to cassava fluid. Corrosion rates of mild steel (10.595 mm/yr), galvanized steel (11.26 mm/yr) and aluminium (9.556 mm/yr) sheets exposed to cassava fluid were got using weight loss technique. The weight loss of each sample for specific periods of immersion (120,168,216, 264 and 312 h) was determined on average of two samples exposed under same cassava fluid in different plastic containers. It was found that aluminium samples had highest corrosion resistance followed by mild steel then galvanized steel. Also corrosion rates for all metallic samples studied decreased over the immersion durations.

Key words: Electrochemical, properties, metals, cassava, fluid**.**

INTRODUCTION

The wastage of metal due to corrosion has become an important engineering problem. Probably, no other source of waste except that affecting human life is of greater concern to all. It has well been said that only through the elimination of waste caused by corrosion and the increase in our national efficiency we can hope to lower the cost of living on one hand, and raise our standard of living on the other. The elimination of waste is a total asset. It has no liabilities (Fontana, 1986).

Corrosion is a chemical or electrochemical reaction between a metal and its environment which involves removal of the metal or its conversion to an oxide or other compound (Walker, 1980). Corrosion occurs in different forms in metallic structure such as in the construction industries, industrial process equipment and allied industries (Abiola and Oforkar, 2002). Corrosion was also represented in global perspective as a tremendous economic loss and much as to be done to combat it (Adetunji and Adewoye, (2010).

Cassava, *Manihot esculenta* Crantz, is a perennial woody shrub with an edible root, which grows in tropical and sub- tropical areas of the world (Burrelli, 2003). Cassava is one of the most important food crops in the tropics. Cassava is a tropical root crop that serves as a food security and income generation crop for many millions of people in the developing world (Scott et al., 2002). Cassava is grown widely in Nigeria and in many regions of the tropics, where it serves as one of the basic food source for about 200 to 300 million people. In 1999, Nigeria produced 33 million tonnes making it the world's largest producer (Sobowale et al., 2007). During fermentation of grated cassava tuber (fufu - local food popular among South Western Nigerians made from cassava tuber), lactic acid bacteria, yeast and other bacteria contribute significantly to starch breakdown, acidification, detoxification and flavour development (Oyewole, 1991). Lactic acid bacteria are found to be useful in flavouring foods, in inhibiting spoilage bacteria and pathogens, in intestinal health and other health benefits related to blood cholesterol levels, immune competence and antibiotics production.

Wider utilization of cassava products can be a catalyst for rural industrial development and raise the incomes of producers, processors and traders. It can also contribute to the food security status of its producing and consuming households (Fontana, 1986). Besides starch, the cassava tuber contains some soluble carbohydrates, that is glucose and sugar, which can be inverted poisonous prussic acid. The nutritive value for cassava tuber is estimated at 127 calories per 100 g to contain protein

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(0.8 to 1.0%), fat (0.2 to 0.5%), carbohydrate (32%), ash (0.3 to 0.5%), moisture (65%) and fibre (0.8%). Cassava is considered to reflect different level of cyanogenic glucosides, the precursor of the highly toxic cyanic acid. Common synonyms are hydrocyanic acid and prussic acid.

Mild steel which accounts for a great deal of metallic material in the construction industries, industrial process equipment and allied industries is susceptible to various forms of corrosion such as pitting corrosion, uniform corrosion, intergranular corrosion, stress corrosion cracking and fatigue corrosion (Afolabi, 2005).

Sacrificial protection involves attaching blocks of zinc to the iron or steel. Sacrificial protection is sometimes used on ships' hulls, below waterline. As zinc is above iron in the reactivity series, it will corrode in preference to iron – the zinc blocks are sacrificed to protect the iron, hence the name "sacrificial protection".

Aluminium is one of the most abundant metals in the earth's crust and its supply is limited by the economics of mining, extracting and processing. Because of their light weights and mechanical strength, aluminium and its alloys are very active material for engineering applications. Since the 1950's, galvanized steel has remained the principal material of construction for factory assembled cooling towers. This fact attests to the cost-effectiveness of galvanized steel, and when properly maintained this material can offer 20 years or more life expectancy in cooling applications.

A galvanized steel sheet includes a galvanized coating layer having a coating weight of about 20 to 60 g/m^2 formed on at least one surface of the steel sheet, and a zinc phosphate coating layer having a coating weight of about 0.5 to 3.0 g/m^2 formed on the galvanized coating layer.

This steel sheet exhibits superior perforative corrosion resistance. The steel sheet also exhibits superior press workability by further controlling the magnesium, nickel, and manganese contents. Zinc is a highly reactive metal. It exhibits a low corrosion rate only if a continuous passive film forms on the surface. A key requirement of corrosion control with zinc is that the surface needs to remain largely dry and in contact with the air in order to develop and maintain this passive film. Storage stain (white rust) is simply the chemical compound, zinc hydroxide/carbonate zinc/oxide zinc, which forms when zinc is kept in contact with moisture during storage or transportation. Zinc corrosion products are typically white, but under certain conditions may also take the form of a grey or black deposit on the metal surface. Accelerated corrosion of galvanized steel pole, white rust and storage stain (tiger striping) can occur when galvanized surfaces are held for extended periods in wet conditions immediately after the hot dip process. The surfaces may become wet either by rain fall or by condensation. The corrosion products form after zinc reacts with moisture. Corrosive compounds such as chlorides from marine and sulphur containing atmospheres accelerate the formation of white rust. The corrosion of galvanized steel cooling towers may be referred to as white rust and the consequence of white rust can be premature failure of galvanized steel components (Amuda et al., 2006).

The only impending factor to achieving the laudable objective of fabrication and installation of machineries for processing of cassava and its product by agro-processing equipment fabrication factories is the frequency at which the machineries break down due to the corrosion of the parts resulting from its contact with cassava juice during processing. It is important to study and identify the corrosion rate of mild steel, galvanized steel and aluminium when used as machine parts of agro-processing equipment fabrication factories with reference to time variation and pH values of contact fluid. Also, providing possible guide lines to selection of material for fabrication of processing machineries to minimize cost of production, maintenance (replacement) and, durability of machine.

Selection of appropriate material for the fabrication of cassava processing machineries was the major objective of this study. The specific objectives were as follows:

(1) Comparison of the corrosion rates of mild steel; galvanized steel and aluminium sheets in cassava fluid.
(2) Evaluation of corrosion performance of mild steel; galvanized steel and aluminium sheets in cassava fluid at different time of immersion.
(3) Effect of pH of cassava fluid on the corrosion performance of mild steel, galvanized steel and aluminium sheets.

This study was carried out with limitations to three test specimens or samples that is, mild steel, galvanized steel and aluminium.

MATERIALS AND METHODS

The materials used for this study were mild steel sheet samples (0.6, 1.0 and 1.46 mm), aluminium sheet samples (0.9 and 1.3 mm), galvanized steel sheet samples (0.36, 0.6 and 1.24 mm), undiluted cassava fluid, plastic containers, dilute sulphuric acid (H_2SO_4), distilled water, alcohol (acetone), serviette papers, paper tape, plastic bowls; apparatus- sensitive weighing balance, pH meter, quant meter, fissions instrument (applied research laboratory 2460), bench shearing machine.

The weights of the samples were recorded using the sensitive weighing balance. Each weighed sample was separately and fully immersed into plastic container filled with cassava fluid (test medium). The fluid was sourced by grinding pilled cassava tuber and squeezing out the fluid using cloth sieve. The containers were first washed with detergent, rinsed in distilled water, and cleaned and dried with towel and tissue paper.

The experimental procedure adopted for this study was total immersion test method because of good reproducibility. Weighed test samples were separately and fully immersed in the test medium of each of the seventy eight plastic containers and were studied for periods of 120, 168, 216, 264 and 312 h at ambient temperature. After the lapse of each period, two of test specimens designated to each of the periods were washed with distilled water, rinsed with acetone, dried with the serviette paper, re-weighed with

Table 1. Mild steel chemical composition in %.

MS sample (mm)	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Fe
0.6	0.07112	0.10080	0.0358	0.0168	0.35353	0.04995	0.10808	0.04773	0.11297	99.1033
1.0	0.07364	0.09610	0.0228	0.0055	0.34188	0.03923	0.12260	0.04771	0.08184	99.1687
1.46	0.04855	0.08184	0.0328	0.0145	0.30990	0.03700	0.11043	0.04618	0.06563	99.2531

Table 2. Aluminium chemical composition in %.

Al sample (mm)	Fe	Si	Mn	Cu	Zn	Ti	Mg	Pb	Sn	Al
0.9	0.493	0.194	0.005	0.004	0.003	0.015	0.000	0.001	0.010	99.77
1.3	0.454	0.183	0.032	0.035	0.052	0.011	0.002	0.006	0.003	99.17

Table 3. Corrosion rates for mild steel (0.6, 1.0 and 1.46 mm).

Sample	Mild steel (0.6 mm)			Mild steel (1.0 mm)			Mild steel (1.46 mm)		
Time (h)	CR (mm/yr)	pH	W/A (kg/m^2)	CR (mm/yr)	pH	W/A (kg/m^2)	CR (mm/yr)	pH	W/A (kg/m^2)
120	4.3	4.0	45.9	6.2	4.2	67.4	10.6	4.0	114.2
168	3.1	4.0	46.4	5.3	3.9	80.4	7.8	3.9	117.8
216	2.4	3.9	46.8	4.2	3.8	82.4	6.2	4.3	119.9
264	2.0	3.9	47.6	3.4	4.1	81.0	5.1	4.5	121.1
312	1.7	4.1	48.5	2.9	4.6	82.1	4.2	4.0	118.4

the sensitive weighing balance and the pH values of the test medium were also measured with a pH meter. The weight recorded was the average of two reading. The weights of the specimens after soaking and the pH readings were recorded.

Calculation

The weight loss of each designated sample at respective immersion period was determined and the corresponding corrosion rate in millimetre per year (mm/yr) was calculated according to the relationship.

The corrosion rate (mm/yr) =KW / DAT

Where: K = 87.6 which is universal constant based on dimension,
W = weight loss (mg),
D = density of test specimen (g/cm^3),
A = area of test specimen (cm^2),
T = time of immersion (h).

RESULTS

Comparative study of galvanized steel, aluminium, and mild steel samples corrosion rates in cassava fluid

The corrosion rates of mild steel (0.6 mm) ranged from 4.263 to 1.729 mm/yr for immersion time of 120 to 312 h while that of galvanized steel ranged from 4.905 to 2.234 mm/yr for the same period. Corrosion rates of 1.0 mm aluminum sample ranged from 6.582 to 2.506 mm/yr.

The weight losses per specimen surface area of the mild steel samples 0.6 mm, 1.0 mm and 1.46 mm thickness as a function of the time of immersion had an average trend (Tables 1 to 3).

This can be related to formation of lactic and formic acid during the fermentation of cassava fluid. This increases the acidity of the cassava fluid and in turn causes the mild steel in contact with it to corrode. The pH of the cassava fluid varied over the times of immersion that implies that the corrosion products of the mild steel had impacts on the pH of the cassava fluid due to formation of iron cyanide.

The weight losses per specimen surface area of these samples with reference to time of immersion had an averagely decreasing trend. The performance of the aluminium was observed to be consistent (Tables 3 and 4). This can be attributed to the formation of aluminium oxide which protects the surface of the aluminium samples and the stability of the oxide in environment with pH between 4 and 9 according to findings in the literature of this study.

DISCUSSION

The decreasing trend of corrosion rates of samples with immersion time (Figures 1 to 4) can be related to formation

Table 4. Corrosion rates for aluminium sheet (0.9 and 1.3 mm).

Sample	Aluminium I (0.9 mm)			Aluminium (1.3 mm)		
Time (h)	CR (mm/yr)	pH	W/A (kg/m^2)	CR (mm/yr)	pH	W/A (kg/m^2)
120	6.6	4.1	24.3	9.6	4.1	35.3
168	4.9	4.2	25.6	6.8	4.0	35.4
216	3.6	4.0	24.2	5.3	4.0	35.3
264	3.0	4.0	24.3	4.3	3.9	35.2
312	2.5	3.9	24.1	3.6	3.9	34.8

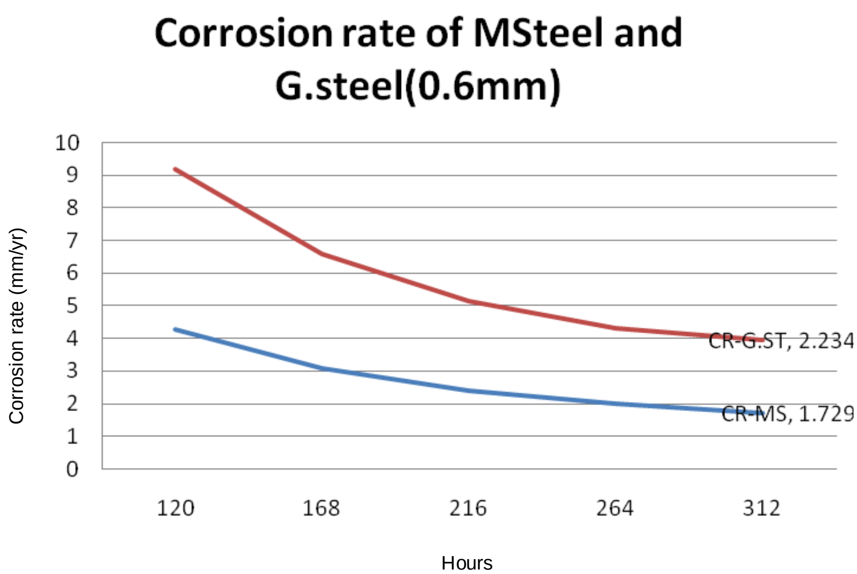

Figure 1. Corrosion rate of mild steel vs. galvanised steel.

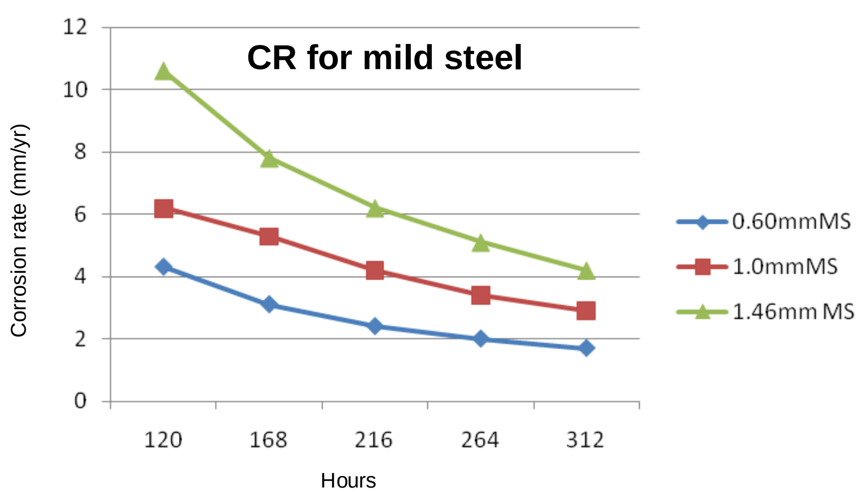

Figure 2. Corrosion rates of mild steel.

of lactic and formic acid during the fermentation of cassava fluid and metallic composition of individual metal as contained in Tables 1 and 2. But the influence of corrosion products which covered the samples lowered the corrosion rates with increase in soaking time. The difference in the corrosion resistance of these samples

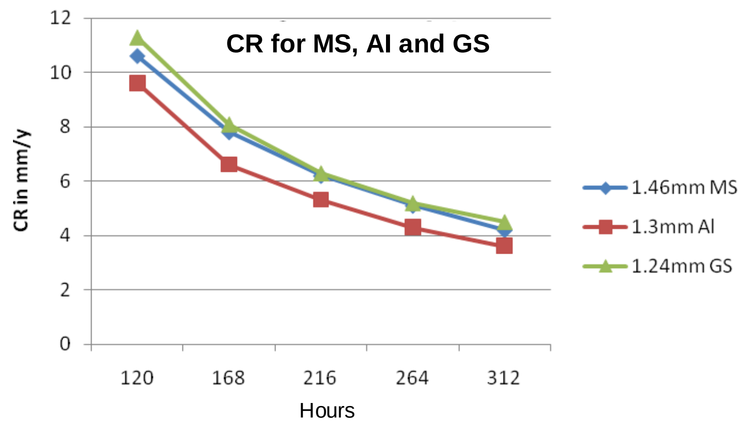

Figure 3. Corrosion rates of mild steel, galvanized steel and aluminium.

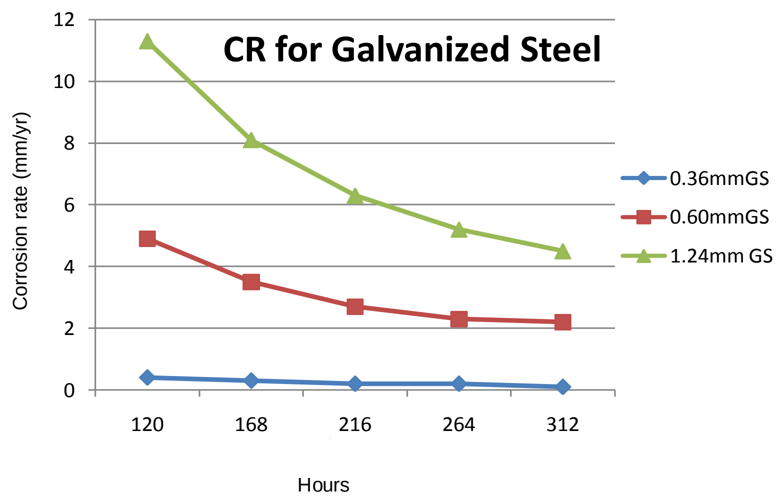

Figure 4. Corrosion rates of galvanized steel in relation to soaking time.

Table 5. Corrosion rates for galvanized steel (0.36, 0.60 and 1.24 mm).

Time (h)	GS (0.36 mm)			GS (0.60 mm)			GS (1.24 mm)		
	CR (mm/yr)	pH	W/A (kg/m^2)	CR (mm/yr)	pH	W/A (kg/m^2)	CR (mm/yr)	pH	W/A (kg/m^2)
120	0.4	4.6	35.6	4.9	5.6	47.9	11.3	4.9	149.9
168	0.3	4.1	37.9	3.5	4.2	47.9	8.1	4.9	110.4
216	0.2	4.4	36.5	2.7	4.3	48.0	6.3	4.1	110.3
264	0.2	4.4	36.1	2.3	4.4	49.9	5.2	4.7	112.1
312	0.1	4.5	35.4	2.2	4.6	56.7	4.5	5.0	113.8

of mild steel (0.6, 1.0 and 1.46 mm thickness) can be explained from the point of view of composition. The variation in the content of elements such as carbon, manganese, silicon, copper, nickel and chromium in mild steel affects the corrosion behaviour of the steel to some degree. The corrosion rates decreased with increasing contents of carbon, manganese and silicon. Both silicon and manganese contents of mild steel 0.6 mm thickness are higher than those of 1.0 mm thickness while carbon, silicon and manganese contents of both mild steel 0.6 and 1.0 mm thickness are higher than those of 1.46 mm thickness.

The purity of 0.90 mm aluminium was higher than that of 1.3 mm. Thus the corrosion rates of the former were higher than those of latter. The corrosion rates of galvanized steel increased with increase in thickness as observed in Table 5. This might be a coincidence as effect of pH which showed the strength of the corrodent

Plate 1. Photomicrograph of aluminium sheet 0.9 mm immersed in cassava fluid (×400; Etched in 2 % Nital and 98% Ethly alcohol).

Plate 2. Photomicrograph of galvanized sheet (0.6 mm) immersed in cassava fluid (×400: Etched in 2 % Nital and 98% Ethly alcohol).

(cassava fluid) was responsible for the increase in corrosion rate. Plates 1 to 3 showed the effect of corrodents on the microstructures of the samples investigated

In summary, the electrochemical properties of the metals – mild steel (0.6, 1.0 and 1.46 mm thickness), galvanized steel (0.36, 0.6 and 1.24 mm thickness) and aluminium (0.9 and 1.3 mm) were investigated in undiluted cassava fluid using weight loss technique. Considering all conditions of same test medium, time of immersion and removal rate, the following conclusions were drawn from the result of the study:

(1) Aluminium had the highest resistance to corrosion followed by mild steel then galvanized steel in cassava fluid.

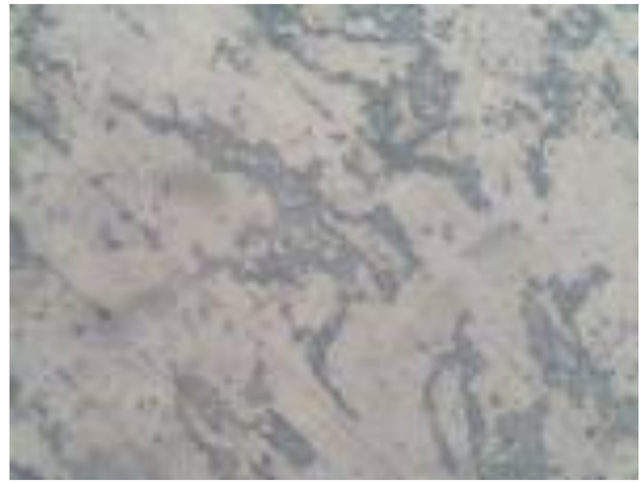

Plate 3. Photomicrograph of 1.0 mm mild steel immersed in cassava fluid (×400: Etched in 2% Nital and 98% Ethly alcohol).

(2) The corrosion rates of the aluminium, galvanized steel and mild steel all had decreasing trend with increase in immersion time in cassava fluid.

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