The effect of cashew juice extract on corrosion inhibition of mild steel in HCl

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AN EVALUATION of the effective performance of juices extracted from *anacardium occidentale* (cashew) on the corrosion inhibition of mild steel immersed in 0.1M hydrochloric acid at ambient temperature was made. Weight-loss and potential measurement techniques were used for the experimental work. The juice extracts were obtained from the bark, nuts, and apples of the tree. The bark-juice extract provides no inhibition for the corrosion of the steel specimen, while the nut-juice extract accelerates the corrosion of the specimen under the conditions of the tests. However, the apple-juice extract at a concentration of 2ml/100ml of 0.1M HCl gives good results of corrosion inhibition of more than average performance, as shown by the calculated inhibitor efficiency.

Introduction

Corrosion phenomena, their prevention, and control have become a perpetual struggle between man and nature, particularly in view of the modern-age technological developments and the increasing need and use of metallic materials in all facets of technology. This issue has necessitated the increasing interest in research into the environment/metal interface reactions and the means of mitigating the damaging effects of corrosion on metals and alloys.

Chemical inhibitors have been very effective in this regard. Various methods and systems are available for use[1-4]. However, to achieve their full protective potential, some discrete time period is generally required. The use of inhibitors in corrosion prevention has been well established and numerous inhibitors have been documented. However, the interest in using juice extracts from plants has been very recent[6-9]. It is believed that there are some active inhibiting chemicals and chemical compounds in plants that can inhibit corrosion in aqueous or acidic environments. Tannin, for instance, has been known to be effective in corrosion inhibition of metals[6].

The bark, nuts, and apples of the cashew tree (*anacardium occidentale*) were used in this work. No attempt has yet been made to analyse the chemical constituents of the juices; this analysis will be done in a further work if any corrosion-inhibition property is clearly established. *Anacardium occidentale* is a medium-sized (6-9m high) spreading-evergreen tree which is widely grown in the tropics for its edible nuts and the resinous oil contained in their shells. The fruit consists of a fleshy, red or yellow, pear-shaped receptacle, termed the 'apple', at the distal end of which is born a hard-shelled, kidney-shaped, ovary or nut. The nut contains a caustic liquid in the shell, which is known to contain 90% anacardic acid and 10% cardol[10]. It is used in the varnish and plastic industries. The cashew apples are too astringent for eating without being processed[10].

In this work, the influence of the juices extracted from the bark, nuts, and apples of the cashew on the corrosion inhibition of

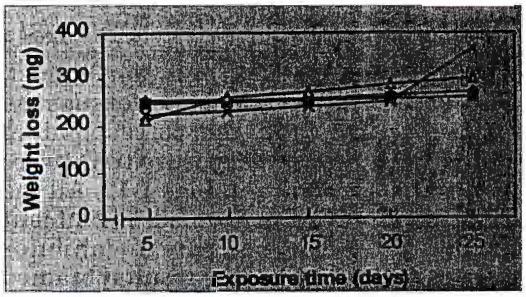


Fig.1. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew bark-juice extract.

◆ = *1ml juice extract/100ml of 0.1M HCl*
■ = *2ml juice extract/100ml of 0.1M HCl*
Δ = *5ml juice extract/100ml of 0.1M HCl*
x = *without juice-extract addition*

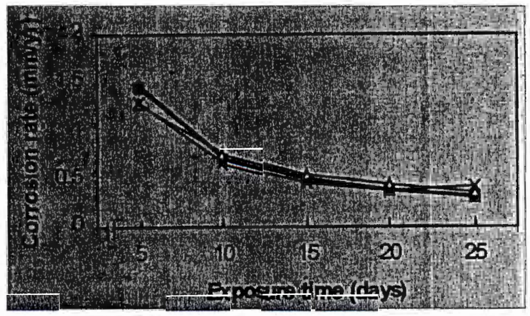


Fig.2. Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew bark-juice extract. The key is as in Fig.1.

mild steel specimens immersed in 0.1M hydrochloric acid has been evaluated. This study will not only make a contribution to the present interest in elucidating the corrosion-inhibitive effectiveness of plants, but is also directed at the possibility of using plant juices as a natural source of inhibitor for corrosion of metals or alloys in corrosive environments. It is important to mention here that literature on this research is still very inadequate.

Experimental procedure

Preparation of specimens

The locally-produced mild-steel test specimen used had a percent nominal composition of 0.15 C, 0.20 Si, 0.04 S, 0.85 Mn, 0.10 Ni, 0.20 Cr, 0.02 Mo, 0.001 V, and 0.35 Cu, the rest being Fe. A cylindrical steel bar was cut into pieces of various dimensions, and a wire brush used to descale the test specimens. They were then ground with silicon carbide abrasive paper, polished, cleaned thoroughly, rinsed in ultrasonic cleaner, dried, and kept in a desiccator for further weight-loss tests. Some of the specimens, after spot welding to the connecting insulated flexible wire were, in turn, mounted in araldite resin. These mounted specimens were prepared for potential measurements of the steel in the test environment.

Test media

The experiment was performed in 0.1M HCl of Analar grade. The separately-extracted juices from the bark, nuts, and apples of the tree were used as the corrosion inhibitor, in different concentrations. This is explained in the following.

Extraction of Anacardium Occidentale juices

The bark, the nuts, and the apples of the cashew tree were collected, separately sliced, and cut into pieces. They were then oven dried in turns at a temperature of 105°C for two hours, and separated into 0.25-kg samples. In turns, the samples were ground into powder and soaked in three different containers containing ethanol. These were filtered and the solution distilled at 79°C to remove the ethanol from the juice extracts and concentrate the inhibiting chemicals. Each of the juice extracts was stored in a clean bottle and properly covered.

Preparation of test media and juice solution extracts

Four measures of 100ml each of 0.1M HCl were put into separate 250-ml beakers. Different concentrations of 1, 2, and 5ml of the juice extracted from the bark of the cashew tree were put separately into the first three beakers; none was put in the fourth beaker. The same process was repeated for the juice extracts from the nuts and the apples, to make the second and third sets of experiments.

Weight-loss experiment

Weighed test pieces were separately and fully immersed for 25 days in each of the beakers containing the HCl and the three sets of extracted juices, as well as for the test without juice addition. Each of the

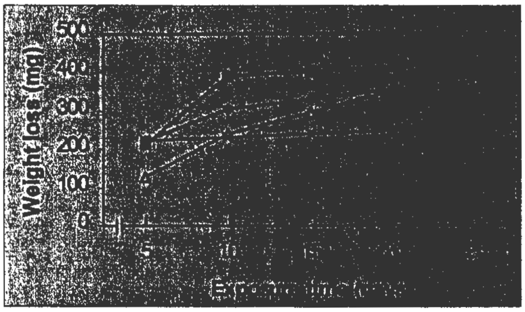
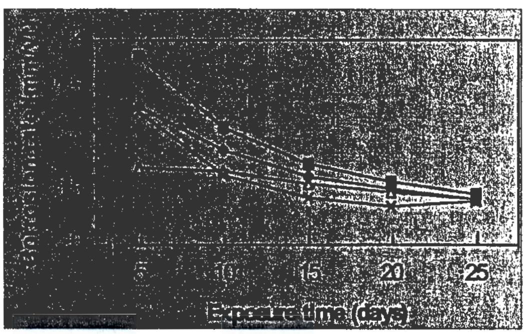


Fig.3. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew nut-juice extract. The key is as Fig.1.

Fig.4 Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew nut-juice extract. The key is as in Fig.1.



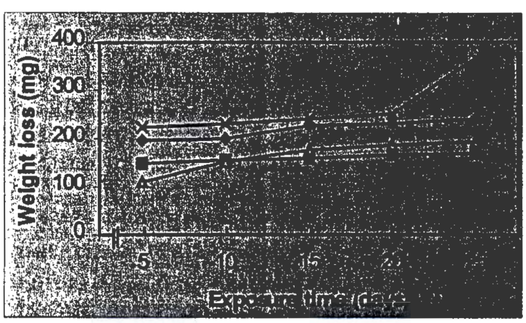


Fig.5 (above)*. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew apple-juice extract. The key is as in Fig.1.*

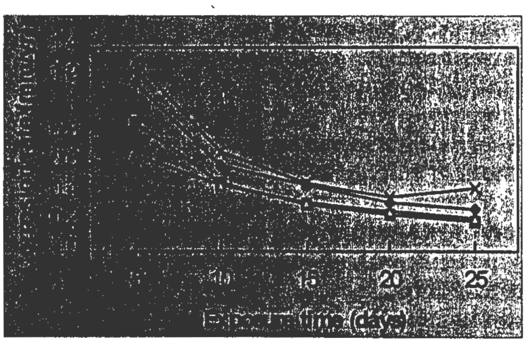


Fig.6 (left)*. Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew apple-juice extract. The key is as in Fig.1.*

test specimens was removed every five days, washed with distilled water, rinsed with methanol, dried and re-weighed. Curves of the weight-loss versus the exposure time, and the corresponding corrosion rate versus exposure time, were made, and are shown in Figs 1-12. All the experiments were performed at ambient temperature. The percentage inhibitor efficiency, P, for each of the results obtained on the last day of the experiment was calculated from the relationship:

$$P = 100\ (1-W_2)/W_1$$

Where W_1 and W_2 are respectively, the corrosion rates in the absence and presence of the predetermined concentration of inhibitor. Table 1 shows the results obtained.

Potential measurements

The mounted and polished specimens were immersed in turns in each of the different test media containing different concentrations of the extracted cashew (*Anacardium Occidentale*) juice. The same tests were also performed in the acid without the juice extract addition. The potential was recorded at five-day intervals using a digital voltmeter and saturated calomel electrode as the reference electrode. The curves of variation of potential (vs. SCE) against exposure time for the data obtained are given in Figs 13-15.

Results and discussion

The bark-juice extract

The results obtained for the variation of weight loss with exposure time for the steel specimens immersed in 0.1M HCl, and with the addition, separately, of varied concentrations of cashew bark-juice extracts (1, 2, and 5ml juice extract/100ml of HCl) are presented in Fig.1. The fourth curve in Fig.1 is for the experiment that contained no juice-extract addition. It is apparent from the figure that no inhibition was conferred at all on the test specimen, at least for the first 22 days of the experiment out of 25 days. In general, the tendency was to an increased or higher

Juice extract	Concentration (ml/100ml HCl)	Corrosion rate (mm/yr)	Inhibitor efficiency (%)
Bark	1	0.32	25.58
	2	0.31	27.91
	5	0.36	16.28
Nut	1	0.44	-2.33
	2	0.50	-16.28
	5	0.45	-4.65
Apple	1	0.29	32.56
	2	0.20	53.49
	5	0.23	46.51

Table 1. Inhibitor efficiency of cashew juice extracts for the mild steel immersed in 0.1M HCl at ambient temperature. (Note: the corrosion rate for the mild steel immersed in 0.1M HCl without any cashew juice extract addition is 0.43mm/yr.)

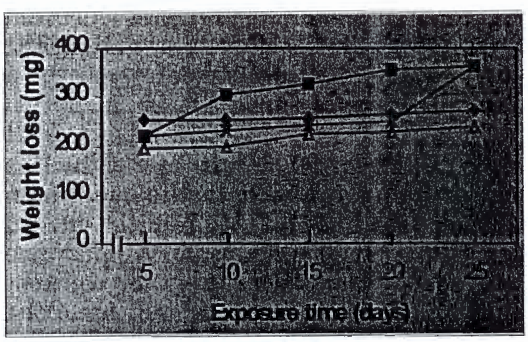


Fig.7. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl and 1ml/100ml HCl addition of the different cashew juice extracts.

◆ = *bark juice extract*
■ = *nut juice extract*
Δ = *apple juice extract*
x = *without juice extract addition*

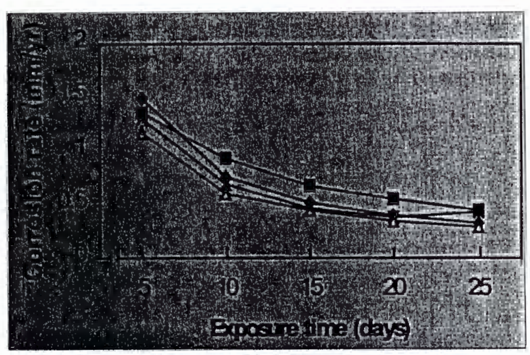


Fig.8. Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl and 1ml/100ml HCl addition of the different cashew juice extracts. The key is as in Fig.7.

corrosion, as indicated by the magnitude of the weight loss.

The weight-loss values obtained are very close indeed. A plausible explanation for this is that the concentrations of the extracted juice inhibitor were not enough to confer passive film on the specimen to prevent or reduce the metal/acid environment interfacial reactions. Characteristically, in a situation where the concentration of an inhibitor is insufficient or is above the optimum level, corrosion of the metal substrate will increase or be accelerated. A situation such as this might have occurred here.

The results as described above for the weight loss vs. exposure time are reflected in the corrosion rate vs. exposure time curves, presented in Fig.2. The decrease in corrosion-rate values with exposure time indicates the increasing weakness of the acid test medium due to the corrosion product(s) in the solution. This contaminant stifled the corrosion reaction increasingly day by day throughout the

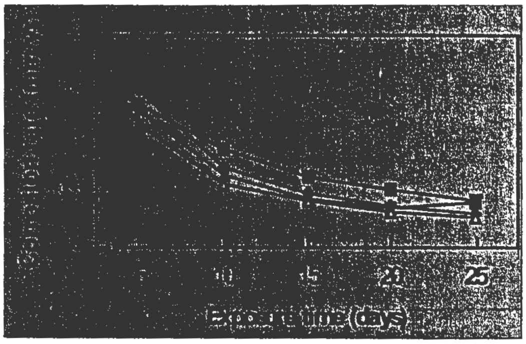


Fig.9. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl and 2ml/100ml HCl addition of the different cashew juice extracts. The key is as in Fig.7.

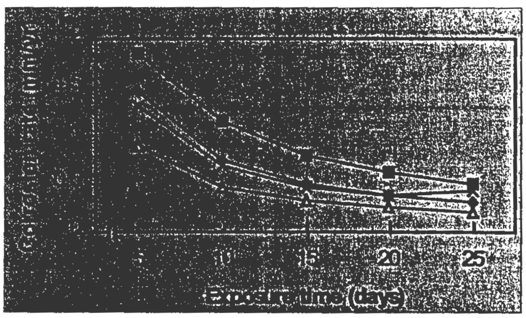


Fig.10. Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl and 2ml/100ml HCl addition of the different cashew juice extracts. The key is as in Fig.7.

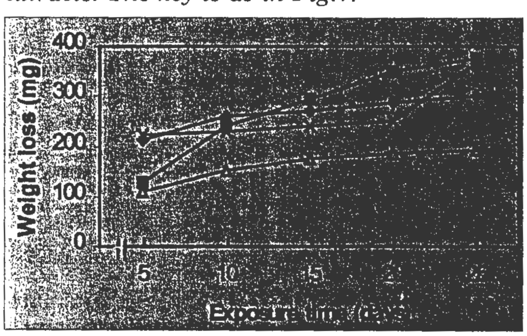


Fig.11. Variation of weight loss with exposure time for the steel specimen immersed in 0.1M HCl and 5ml/100ml HCl addition of the different cashew juice extracts. The key is as in Fig.7.

experimental period. The corrosion-rate values for the tests with the added juice extracts and the one without any juice addition are very close indeed, and there was no obvious inhibition, rather of corrosion of the metal test specimen.

The nut-juice extract

The nut-juice extract at the concentrations used provided no inhibition either, as shown in Fig.3. Weight-loss values - an indicator of corrosion magnitude - are shown here to be higher than those in Fig.1. The same trend is shown in Fig.4 for corrosion rate values relative to the exposure time. With the nut-juice extract addition, at all concentrations, except at the early period of the experiment, a substantial increase in corrosion is indicated. It is difficult to explain these results; however, this increased corrosion phenomenon cannot be unrelated to the concentration of the juice extract used, which would have been insufficient.

The use of juice extracted from the cashew nuts seems to be inappropriate at the level of lower concentrations such as those used, for a strong test medium like hydrochloric acid. Furthermore, the nuts are known[10] to contain caustic liquid in shells - which contain 90% anacardic acid and 10% cardol. These are chemicals that are potent enough to depassivate any inhibitive film that cannot be conferred by tannin. The presence of these chemicals in the extracted juice from the nuts can be associated with the increased corrosion observed in Fig.3, and which is reflected in Fig.4 for corrosion-rate values. Just like Fig.2, the decreasing corrosion-rate values shown in Fig.4 are an indication of the continuous weakening of the test medium by the corrosion-products' contamination.

The apple-juice extract

Fig.5 shows the curves of weight loss vs. the exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew apple-juice extract. The fourth curve is for the test without the juice-extract addition. The observation that the curve for the test without the juice extract has higher values of weight loss (ranging from 221-355mg) throughout the experimental period, confirming the corrosion-inhibitive property of the juice extracted from the cashew's apple. The samples with 2 and 5ml addition show more corrosion inhibition than the 1-ml sample.

The corrosion-rate values, in Fig.6, also reflect the results obtained in Fig.5. While all the tests show a decreasing corrosion rate with exposure time, the tests with 2ml and 5ml apple juice/100ml HCl concentration show the least rate of corrosion. The decreasing trend of the corrosion rate with time has been explained above: cashew apples are very astringent, and they are likely to contain more tannin, hence the corrosion-inhibition property exhibited.

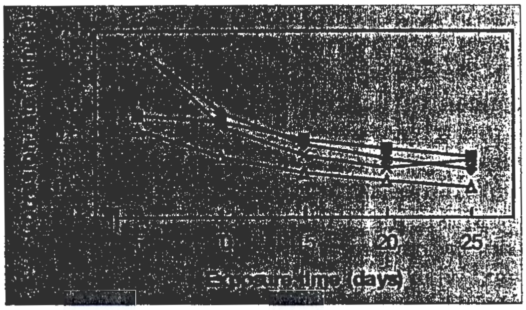


Fig.12. Variation of corrosion rate with exposure time for the steel specimen immersed in 0.1M HCl and 5ml/100ml HCl addition of the different cashew juice extracts. The key is as in Fig.7.

Performance of the juice extracts at the different concentrations

The results for the comparative performance (ranking) of the different juice extracts from the bark, nuts, and apples of the cashew tree, when added in different concentrations to the acid test environment, are presented in Figs 7-12. Fig.7 shows the curves of weight loss vs. exposure time for the steel specimen immersed in 0.1M HCl and 1ml/100ml HCl addition of the different juice extracts. Clearly, the apple juice is the only extract that had some inhibitive impact. The bark- and nut-juice extracts increased the corrosion instead of inhibiting. The same trend is shown in Fig.8 for the corrosion rates. Though the corrosion-rate values are close, the apple juice still had the lowest value (at 0.29mm/yr on the 25th day of the experiment).

Figs 9-12 show the weight loss and corrosion rate vs. the exposure time for the juice-extract addition at the concentrations of 2ml and 5ml/100ml HCl, respectively. The same trend in ranking as in Figs 7 and 8 is also shown here. The apple-juice extract further shows distinct corrosion-inhibition and lower corrosion rate values in all the results. However, its corrosion-inhibition performance at the concentrations of 2ml and 5ml juice/100ml HCl is almost the same in terms of the recorded weight loss values and corrosion rates.

Potential measurements

The curves of the variation of potential (mV) versus saturated calomel electrode (SCE) with exposure time for mild-steel specimens immersed in 0.1M HCl with different concentrations of added cashew-tree bark-, nut-, and apple-juice extracts are presented in Figs 13-15, respectively.

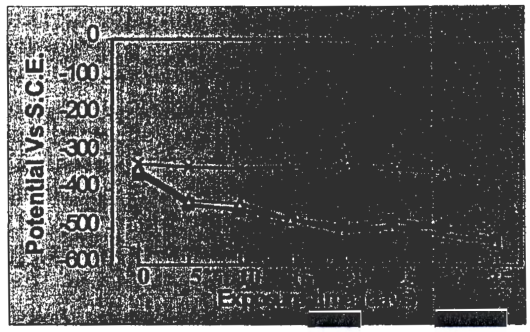


Fig.13. Variation of potential with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew bark juice extract. The key is as in Fig.1.

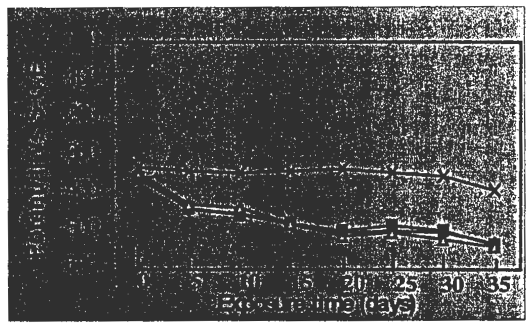


Fig.14. Variation of potential with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew nut juice extract. The key is as in Fig.1.

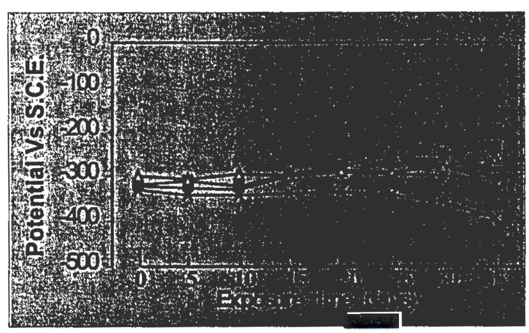


Fig.15. Variation of potential with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew apple juice extract. The key is as in Fig.1.

In all the curves in each of the figures the results obtained bear a close relationship to the trend in Figs 1-6.

In Fig.13, none of the bark-juice concentrations show any corrosion-inhibition effect. All the potential values throughout the experimental period are more negative than the experiment without any juice addition. As said before, the concentrations used might be insufficient to create a stable passive film

to inhibit corrosion of the mild steel in the test environment.

Fig.14, which shows the curves for the addition of nut-juice extract, follows the same trend as Fig.13. The observation here is that of the acceleration of corrosion. On average, all the juice concentrations added to the acid test medium achieved, on the last day of the experiment, a potential value of -550mV, while at the same period the test without any juice addition recorded a potential value of -380mV. The results in Figs 13 and 14 are in agreement with the results obtained in Figs 1-4 for the weight-loss method.

Fig.15 shows the variation of potential (vs. SCE) with exposure time for the steel specimen immersed in 0.1M HCl with varied concentrations of added cashew apple-juice extract. Just as in Figs 5 and 6, this is the only juice extract out of the three that gives a fairly good result. All the curves show better performance in terms of potential values than the test without the juice addition, which has more negative potential values that range from -330mV to -390mV. In all the tests with the varied apple-juice concentration addition, the potential values range from -235mV to -330mV. These potential results thus follow the same trend of corrosion inhibition as the results obtained for the weight-loss method. The test with the 2ml apple-juice addition has the least-negative value of the potential (-235mV) on the 25th day of the experiment. The 5ml juice sample, which achieved a potential of -261mV on the last day (25th) of the experiment, also follows this pattern. The juice with 1ml/100ml of HCl performed similarly well, though with a more-negative potential of -330mV on the last day of the experiment.

Inhibitor efficiency

Presented in Table 1 are the results (by calculation) obtained for the inhibitor efficiency of the various juice extracts used at different concentrations. The inhibitor efficiency of all concentrations of the bark-juice extract is very low - the highest being 27.91% at 2ml extract/100ml HCl. For corrosion prevention, this result is inconsequential and is in agreement with the results obtained with the weight-loss and potential measurements.

The negative percentage values obtained for the inhibitor efficiency of the nut-juice extract at all concentrations indicate that the juice accelerated the corrosion of mild steel specimens in the HCl test medium instead of inhibiting it. The reason for this phenomenon has been explained above.

The apple-juice extract at all concentrations (1, 2, and 5ml/100ml HCl) used gives positive inhibitor-efficiency values. The best result of 53.49% efficiency was obtained with the addition of 2ml apple-juice extract/100ml of HCl concentration. The 5ml-juice extract comes next with 46.51%. The striking observation with the apple-juice extract is that, at 2ml-juice extract addition, the optimum level of juice addition appears to have been reached. This is because, with the 5ml-juice addition, the inhibitor efficiency reduces; and at 1ml juice addition, the percent inhibitor efficiency is just 32.56%.

All the results obtained for the inhibitor efficiency follow the same trend as the results obtained with the weight-loss and potential measurements. No test was performed for the synergistic effect of the juices because of the low values recorded for the bark juice and the negative values for the nut-juice extract.

Conclusion

1. The bark-juice extract, at the concentrations used, cannot inhibit the corrosion of mild steel in 0.1M HCl at ambient temperature.

2. The nut-juice extract, at the concentrations used, is unsuitable for use as a corrosion inhibitor for the mild steel at a HCl concentration of 0.1M, as it accelerates corrosion of the steel.

3. The good result obtained with the use of apple-juice extract indicates its viability as a corrosion inhibitor for mild steel in 0.1M HCl at the ambient temperature if the right concentration, such as the 2ml juice extract/100ml HCl, is used. However, the inhibitor efficiency is just barely above the average.

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Comment

(continued from page 34)

be expected on the basis of their higher strength alone.

7. However, HSLA offshore steels exhibit considerable variability in their susceptibilities to hydrogen embrittlement. It is recommended that each type of steel should be considered individually and should be subjected to thorough testing before being accepted for use, particularly in critical locations and in circumstances that could lead to hydrogen charging.

8. The effects of hydrogen charging from cathodic protection should be fully considered, particularly if there is a possibility that over-protection may occur. The use of potential-limiting diodes, or sacrificial anodes with a less-protective potential, would reduce the risk of hydrogen-assisted cracking occurring in susceptible steels.

9. Sulphides generated by microbial activity in the marine environment can cause a substantial increase in hydrogen uptake by freely-corroding and cathodically-protected steel. It is recommended that when high-strength steels are used in conditions where they may be exposed to microbial activity, they should first be evaluated using test environments containing similar sulphide levels.

Long-term durability of passive fire protection coatings

THE UK's Health & Safety Executive (HSE) has recently adopted a project, begun by Shell UK Exploration & Production in the early 1980, to study the long-tern durability of passive fire protection coatings both in terms of their fire performance and their reliability in preventing corrosion of the metal substrate. The real-time weathering, at a maritime test facility, of samples provided by all of the leading manufacturers, and regular monitoring, including fire testing, has to date revealed some reassuring results. However, newer products and more severe fire resistance requirements demand further study. *Offshore Research*[2] reports that, to address this need, the HSE has sponsored its Health & Safety Laboratory to continue this important project, which has been extended to include jet fire testing of weathered

2 Offshore Research Focus, May, 2000. Published by the HSE Research Strategy Unit, Liverpool, UK, fax: (+44) 0151 951 3098.