Inhibition of cashew juice on the corrosion of mild steel in sulphuric acid

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THE INHIBITION of juice extracts of cashews (*Anacardium Occidentale*) on the corrosion of mild steel test specimens immersed in 0.5M H_2SO_4 at ambient temperature was evaluated. The weight-loss method and potential-measurement technique were used for the experimental work. The juice was obtained from the bark, apples, and nuts of the tree: the bark juice extract provided a fairly good inhibition performance at a concentration of only 0.5ml juice per 100ml of acid; the nut juice extract, at all concentrations used, provided very minimal corrosion inhibition of the test specimen in the acid; the cashew apple juice gave more-than-average performance of inhibition of the test specimen at all the concentrations used.

RECENT RESEARCH work on the inhibitive properties of plants has received attention [1-4], although literature on this research subject has been minimal. The use of plant juices as inhibiting additives to a corrosive test media has, in most cases, been the focus of attention. Tannin – present in the juices from plants – has been associated with the corrosion inhibition obtained in the investigations [1]. Chemical inhibitors have been of significant use in effectively mitigating against the damaging effects of corrosion of metals and alloys when in interaction with a corrosive environment and, in this context, various methods and systems are available for use [5-8].

In the current work, the barks, nuts, and apples of the cashew tree (Anacardium Occidentale) were used. The cashew is a medium-sized spreading evergreen tree which is widely grown in the tropics; its nuts are edible, and the shells contain resinous oil. The fruit consists of a fleshy, red or yellow, pear-shaped receptacle, termed the apple, at the distal end of which is borne a hard-shelled, kidney-shaped, ovary or nut. The shells of the nuts contain caustic liquid, and is known to contain 90% anacardic acid and 10% cardol [10]. Because of the astringent nature of the cashew apples, they cannot be eaten without being processed [9].

This work reports the results obtained in the evaluation of the corrosion inhibitive effectiveness of the juice extracts from the bark, nuts, and apples of the cashew on the corrosion of mild steel specimens immersed in 0.5M H2SO4. This investigation is a part of a series of work that looks at the possibility of using plant juice extracts as a natural source of inhibitor to mitigate against the corrosion of metal in corrosive environments. The anticipation is that the study will make a contribution to the present research interest and attempts in determining the corrosion-inhibiting properties and the effectiveness of plant-

Juice extract	Juice extract concentration (mm/100ml H_2SO_4)	Corrosion rate (mm/yr) (in the presence of juice extract)	Inhibitor efficiency (%)
Bark	0.2	0.84	18
	0.5	0.43	65
	1	0.81	22
Nut	0.2	0.71	33
	0.5	0.70	34
	1	0.68	36
Apple	0.2	0.43	65
	0.5	0.44	64
	1	0.40	68

Table 1. Inhibitor efficiency of cashew juice extracts for the mild steel immersed in 0.5M H_2SO_4 at ambient temperature.

juice extracts. A positive result will be of technological importance.

Experimental procedure

Preparation of specimens

The mild-steel test specimen used had a nominal percentage 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, 0.35 Cu, the rest being Fe. A cylindrical steel bar was cut into various pieces of different lengths, and the specimens were descaled by wire brushing. They were then ground with silicon carbide abrasive paper of 240, 320, 400, and 600 grits; polished to 1micron, cleaned, thoroughly rinsed in ultrasonic cleaner, dried, and kept in a desiccator for further weight-loss tests. Some specimens were, in turn, mounted in available resin after spot welding to connecting insulated flexible wire; these specimens were prepared for potential measurements of the steel in the test environment.

Test media

The experiments were performed in 0.5M sulphuric acid, of AnalaR grade. The juices used as the corrosion inhibitor were separately extracted from the bark, nuts, and apples of the cashew tree, and were prepared in different concentrations as described below.

Extraction of cashew juice(s)

The bark, nuts, and apples of the tree were cut separately into pieces which were then oven dried at 105°C for two hours, cooled, and trimmed to be uniformly 0.25kg each. They were separately ground into powder, and soaked in three different containers containing ethanol for five days in order to extract the juice by leaching. Each of the different juice extracts in each container was filtered at the end of the soaking period. The solutions were distilled at 79°C to remove the ethanol from the juice extracts and concentrate the inhibiting chemical(s). Each of the juice extracts (the respective distillates) was stored in a clean bottle and covered properly.

Preparation of the test media and juice extracts

100ml of 0.5M H_2SO_4 was measured into four different 250-ml beakers. Different concentrations of 0.2, 0.5, and 1.0ml of the juice extracted from the bark of the tree were separately put into the first three beakers, and the fourth beaker was kept plain, without any juice addition. This process was repeated for the juice extracts from the nuts and the apples. These make the second and third sets of experiments, respectively.

Weight-loss experiment

Weighed test pieces were separately immersed for 25 days in each of the beakers that contained the acid and the extracted juices, for the three sets described above, and also for the test without juice addition. Every five days, each of the steel specimens was removed from the test environment, washed with distilled water, rinsed with methanol, dried, and re-weighed. Curves of the corrosion rate versus exposure time were made, and are presented in Figs 1-12. The experiments were all 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 inhibitor. The results obtained are presented in Table 1.

Potential measurements

The potential-monitoring method was used to test for the corrosion and protection behaviour of the steel specimens in the test environments. The mounted and polished specimens were immersed in turn in each of the different test media, which contained different concentrations of the extracted cashew juice. The potential was recorded at five-day intervals using a digital voltmeter and a saturated-calomel electrode as the reference electrode. The same test was performed in the acid test medium without the juice extract addition. The curves of variation of potential (vs SCE) with exposure time are presented in Figs 13-15. The free corrosion potential measurements were performed at ambient temperature.

Results and discussion

The bark juice extract

The results obtained for the variation of weight loss with exposure time for the steel test specimen immersed in the acid are presented in Fig.1. Varied concentrations of the cashew bark juice extract (0.2, 0.5, and 1.0ml per 100ml acid) were separately added to the acid solution; the fourth curve in Fig.1 is for the experiment performed in the plain acid without the juice extract addition. It is clear from the results that the only corrosion inhibition was provided by addition of 0.5ml juice per 100ml of the acid to the test medium; at this inhibitor (juice extract) concentration, the weight loss value recorded on the 25th day of the experiment was 341mg. The other concentrations of juice extract did not provide any corrosion inhibition on the test specimens, as they have higher weight loss values (667mg for 0.2ml and 640mg for 1.0ml) than on the last day of the experiment.

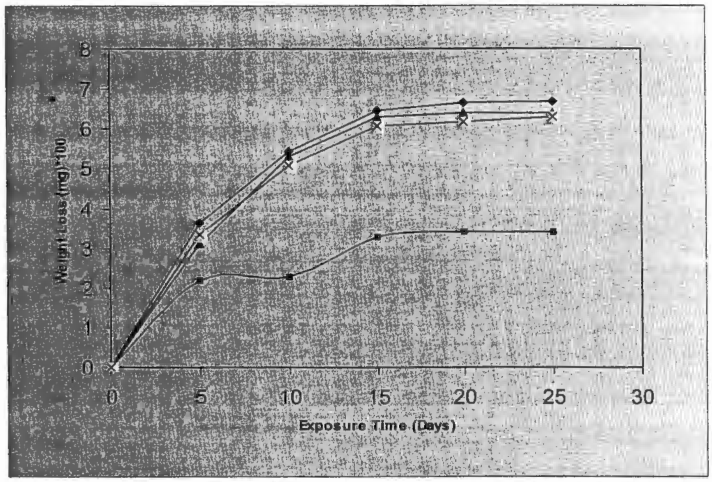


Fig.1. Variation of weight loss with exposure time for the steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew bark juice:

◆ = *0.2ml juice extract / 100ml of acid*
■ = *0.5ml juice extract / 100ml of acid*
▲ = *1ml juice extract / 100ml of acid*
x = *without juice extract*

Characteristically, inhibitors work effectively at the optimum level. With the 0.2-ml addition, the concentration might not be enough to inhibit corrosion, while with 1.0-ml juice extract addition, the optimum level seems to have been exceeded. An inhibitor concentration below or above the optimum level of concentration will not inhibit corrosion, but will rather accelerate it. This characteristic could be what happened with the result described above.

The corresponding corrosion rate versus

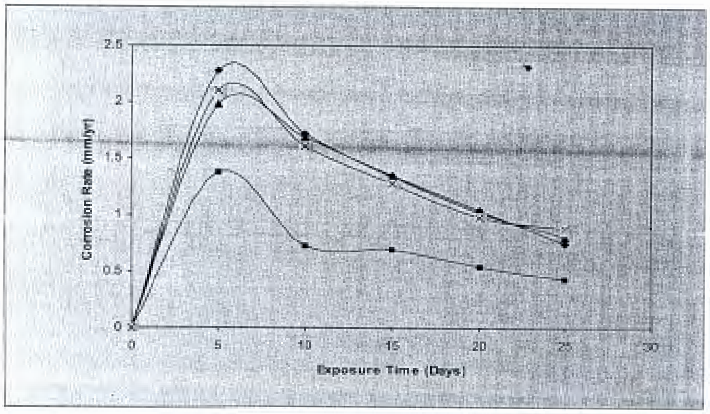


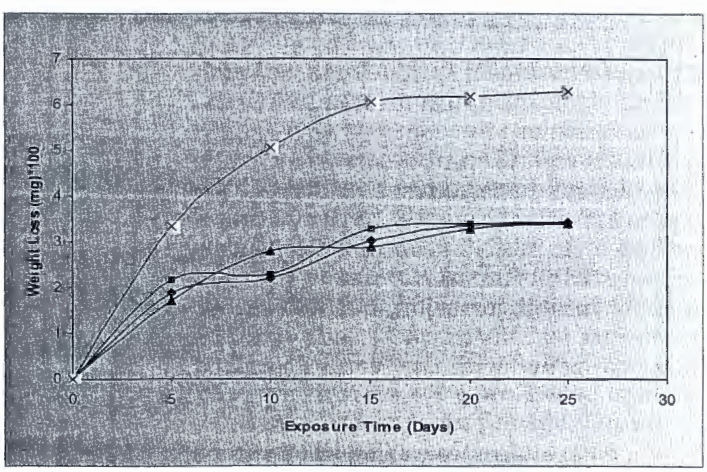
Fig.2. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew bark juice. The key is as in Fig.1.

the exposure time results, presented in Fig.2, bear a correlation with the results in Fig.1: all the corrosion rate values decreased with increase of the experimental exposure time. This tendency can be explained to be due to the weakening of the test medium by the corrosion products which had contaminated the acid and hence stifled the corrosion reactions. Just as in Fig.1, the lowest corrosion rate values were obtained with the experiment performed with the addition of 0.5 ml juice extract per 100ml acid; the initial corrosion rate value on the fifth day of the experiment was 1.38mm/yr which, on the last day of the experiment, had reduced to 0.43mm/yr. The other juice extract additions showed corrosion rate values that were, in general, higher than the values obtained for the test in the plain acid. This confirms the increase in corrosion caused by the addition of the 0.2 and 1.0ml juice extracts per 100ml acid, and the reason given above for this type of observation is also applicable here.

Fig.3. Variation of weight loss with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew apple juice. The key is as in Fig.1.

The apple juice extract

The results obtained for the variation of weight loss with exposure time for the specimen immersed in 0.5M acid and with added varied concentrations (0.2, 0.5, and 1.0ml juice extract per 100 ml of acid) of cashew apple juice extract are presented in Fig.3. The curve of the test without any juice extract addition clearly shows the highest weight loss values, achieving 629mg on the 25th day of the experiment. The addition of the various concentrations of the apple juice extract shows significant reduction in the recorded weight loss values, which indicate the magnitude of corrosion. In this case, it can be said that a reasonable degree of corrosion inhibition of the test specimen in the acid medium was provided. All the three different concentrations of the cashew's apple juice extract give very close values of weight loss on the 25th day of the experiment; however, the 1-ml juice addition had an initial better performance (321mg weight loss) than the 0.2-ml (343mg) and 0.5-ml juice (339 mg) additions.



The corresponding corrosion rate curves obtained by calculation from the data in Fig.3 are presented in Fig.4. The corrosion rates are very low; with the three different juice concentrations achieving values which range from 0.40 (1.0ml juice), 0.44 (for 0.5ml juice) to 0.43mm/yr (for 0.2ml juice extract per 100 ml acid). The test without any juice extract addition gave higher corrosion rate values throughout the experimental period. These results thus confirm that the apple juice of the cashew possesses corrosion-inhibiting property. It is not certain, however, whether the optimum concentration needed for more-effective corrosion inhibition have been reached with any of the three concentrations used.

The decreasing trend of the corrosion rate with the exposure time is an indication of the weakening of the test environment by the corrosion deposit, which stifled the corrosion reactions. It is known that the cashew apples are very astringent – a property which is associated with the presence of tannin. The presence of tannin to a reasonable concentration in the juice would have been largely responsible for the exhibited corrosion inhibition property of this juice extract.

The nut juice extract

When the weight loss values of the tests with the nut extracts were compared with the test without any juice extract addition, the nut juice extract in the three different concentrations used provided very little corrosion inhibition, Fig.5. Though the values recorded were lower for the tests with juice addition for the test without any juice, all the recorded weight loss values were generally high. The lowest, on the 25th day of the experiment, was 525mg for 1.0ml juice; the corresponding values for the 0.2-ml and 0.5-ml juice additions per 100ml acid concentration were 567 and 562mg, respectively; that for the test without juice addition was 629mg.

The variation of corrosion rate with the exposure time, Fig.6, follows the same trend as in Fig.5. The test without juice addition has a high corrosion rate, although this is not very significant. All the three different concentrations showed little difference in corrosion rates; the decreasing corrosion rates with the exposure time, as explained above, was due to the weakening of the test medium by the corrosion product contaminant of the medium. The very insignificant corrosion inhibition given by the nut juice extract could be due to insufficient tannin concentration in the juice. In addition, the nuts of cashew are known to contain caustic liquid in the shell, which contain 90% anacardic acid and 10% cardol. These are chemicals that are potent enough to depassivate any inhibiting film that could be provided by tannin. The presence of these chemicals in the extracted juice from the cashew nuts can be associated with the minimal corrosion inhibition recorded in Fig.5.

Performance of the juice extracted at different concentrations

Figures 7-12 present the results for the comparative performance(s) of the different juice extracts from the bark, nuts, and apples of the cashew, when added in different concentrations to acid test environment.

The curves of the weight loss vs the exposure time for the specimen immersed in 0.5M H_2SO_4 and 0.2ml/100ml H_2SO_4 addition of the different juice extracts are presented in Fig.7. in which it can be seen that the inhibiting effect of the apple juice extract at the concentration used is significant. The nut juice extract also shows some inhibiting effect, but the effect is low. The bark juice extract shows no corrosion inhibition at all, as the weight loss values are higher than the test without any juice addition. The concentration of corrosion inhibiting chemical(s) (tannin) in the bark

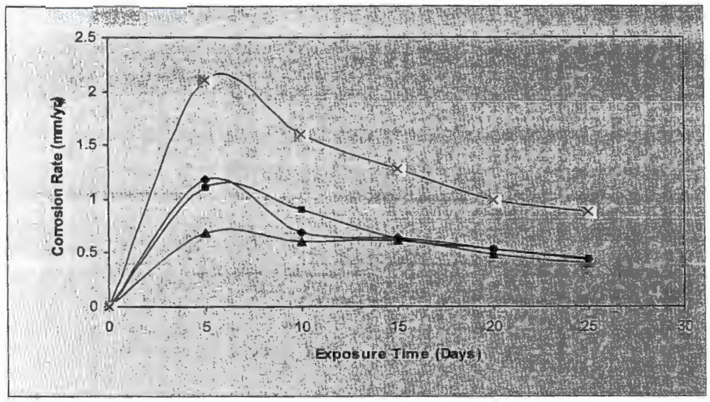


Fig.4. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew apple juice. The key is as in Fig.1.

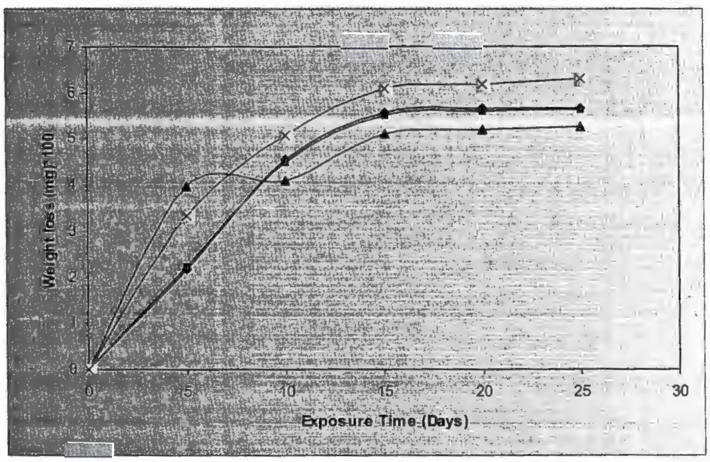


Fig.5. Variation of weight loss with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew nut juice. The key is as in Fig.1.

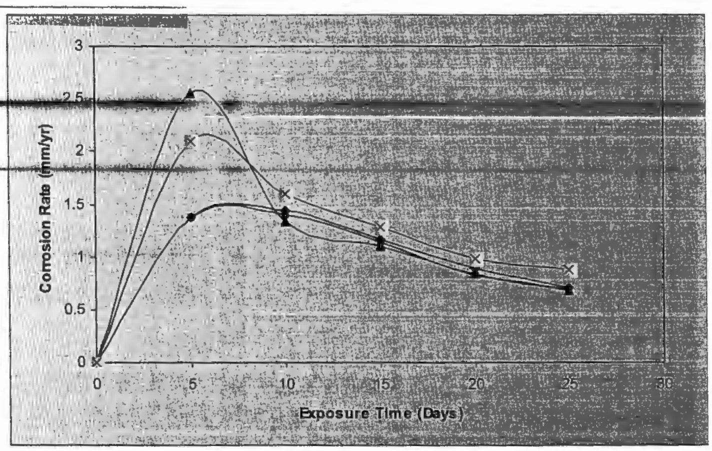


Fig.6. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew nut juice. The key is as in Fig.1.

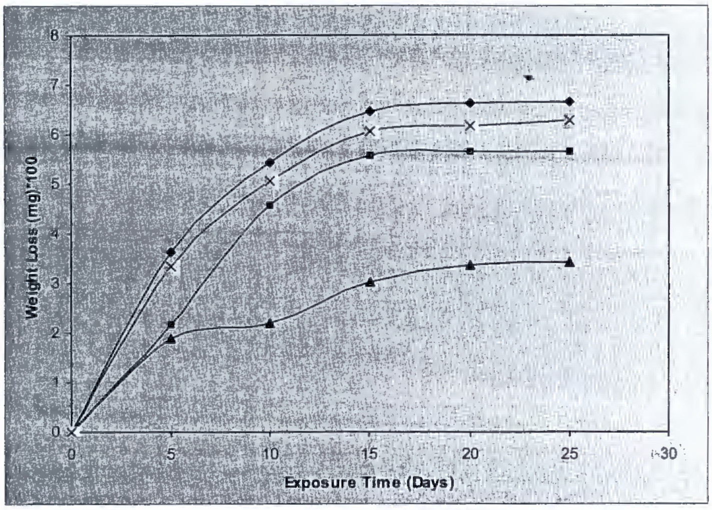


Fig.7 (left). Variation of weight loss with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 0.2ml/100ml H_2SO_4 addition of the different cashew juices:

◆ = *bark juice extract*
■ = *nut juice extract*
▲ = *apple juice extract*
× = *without juice extract*

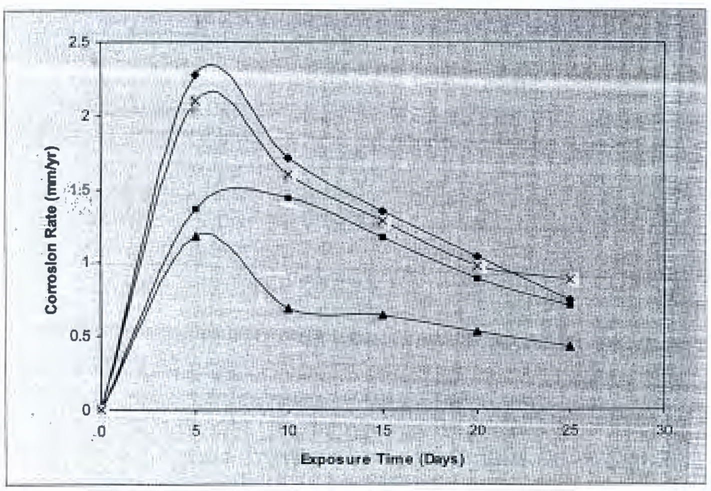


Fig.8. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 0.2ml/100ml H_2SO_4 addition of the different cashew juices. The key is as in Fig.7.

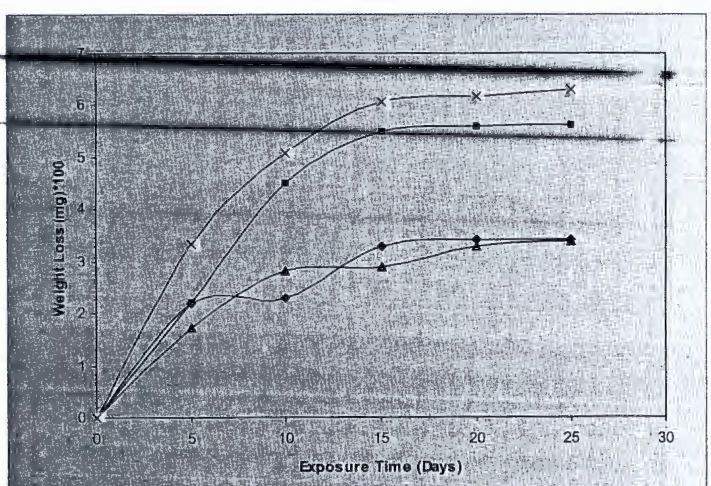


Fig.9. Variation of weight loss with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 0.5ml/100ml H_2SO_4 addition of the different cashew juices. The key is as in Fig.7.

juice used seems to be too low to provide the desired inhibition; it, instead, increased the corrosion. The same trend of corrosion behaviour is shown in Fig.8; with the apple juice extract addition, the corrosion rate was much lower than the others, while the bark juice presented the highest corrosion rate values. The better performance of the apple juice extract, as discussed above, could be associated with the reasonable amount of tannin contained in it, as indicated by its astringent nature. The very-low to poor performance of the nut juice extract could also be associated with its acidic nature, as it is known to contain anacardic acid and a cardol.

When the cashew juice extracts at a concentration of 0.5ml/100ml of 0.5M H_2SO_4 was used as the added inhibitor to the acid test medium, a different result from that of Figs 7 and 8 was obtained, indicated by the curves presented in Fig.9 for the weight loss values relative to exposure time, and in Fig.10 for the corresponding corrosion rate values. In Fig.9, the cashew's apple juice extract still maintains low weight loss values just as with the use of 0.2ml/100ml acid previously discussed. The drastic change, however, is for the bark juice extract, which now maintains about the same average values of weight loss as that of apple juice extract: at the end of the experiment, their weight loss values are respectively 341mg (bark juice) and 339mg (apple juice).

The addition of the cashew's apple juice to the acid test medium maintained a stable and significant corrosion inhibiting behaviour with both the 0.2ml and 0.5ml/100ml of acid concentration. The bark juice, on the other hand, improved its corrosion inhibiting property greatly from its poor performance at 0.2ml to a better performance at 0.5ml/100ml acid. The concentration effect of the reactive chemical species (tannin) that caused the corrosion inhibition of mild steel specimen in the acid test environment is apparent here, in the case of the bark juice extract.

The nut juice extract also gave an improved corrosion inhibiting performance at this concentration (0.5ml/100ml acid). The corrosion rates (Fig.10) behave similarly as in Fig.9 in the performance trend: the corrosion rates for both the apple (0.44mm/yr) and the bark (0.43mm/yr) juices are about the same on average as at the last day of the experiment. The decreasing corrosion rate values with the experimental exposure time, as earlier explained, is due to the weakening of the test environment with time by the corrosion products which contaminated the acid and gradually resulting in stifling the corrosion reactions.

Figures 11 and 12 show the results obtained for the weight loss and corrosion rate vs the exposure time, respectively, for the addition of the different cashew juices when 1ml/100ml H_2SO_4 of each juice extract is used as the inhibitor. The apple juice, as presented in both the Figs 11 and 12, still maintained a stable corrosion inhibiting behaviour of lowest weight loss values and very low corrosion rate. At this concentration of the juice extracts used, the bark juice has now gone back to very-poor corrosion inhibiting performance, as it even tends to accelerate corrosion. Its weight loss values and corrosion rate values are now higher than the plain acid test (without juice extract addition). The inference from this is that the bark juice has its optimum corrosion inhibition performance at a concentration of 0.5ml/100ml H_2SO_4, a phenomenon very characteristic of inhibitors. They are not only specific, but also effective positively at an optimum level, either below or above which their performance becomes adversely affected. The nut juice at this concentration still maintained an effective corrosion inhibition as its recorded weight-loss and corrosion-rate values are below that of the plain acid test values. However, the inhibition magnitude can be described as insignificant as the recorded weight-loss values are still high.

Potential measurements

In Figs 13-15, the curves of the variation of potential (mV) vs a saturated-calomel electrode (SCE) with exposure time for the mild steel specimens immersed in 0.5M H_2SO_4 with different concentrations of added cashew bark, nut, and apple juice extracts, respectively, are presented. The results bear a relationship with those presented in Figs1-6 for the weight-loss method, though with some apparent

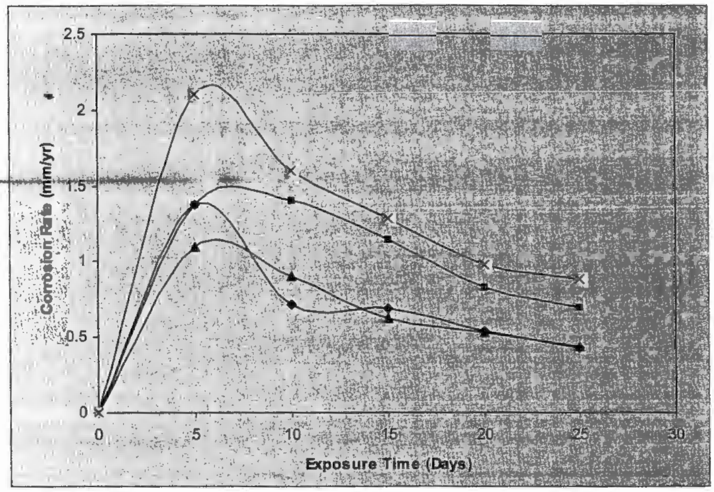


Fig.10. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 0.5ml / 100ml H_2SO_4 addition of the different cashew juices. The key is as in Fig.7.

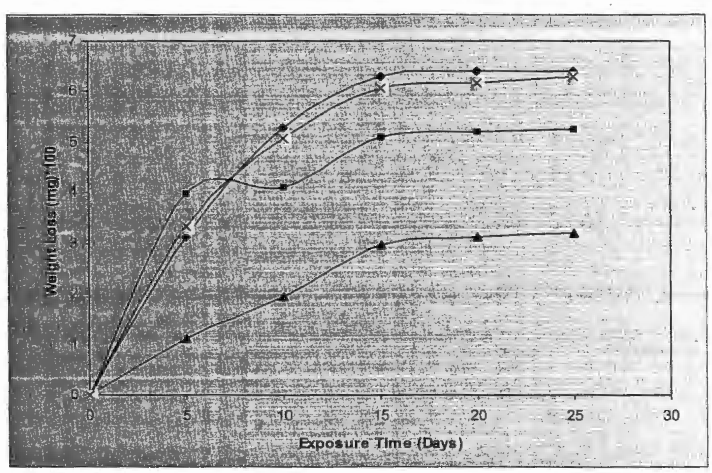


Fig.11. Variation of weight loss with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 1ml / 100ml H_2SO_4 addition of the different cashew juices. The key is as in Fig.7.

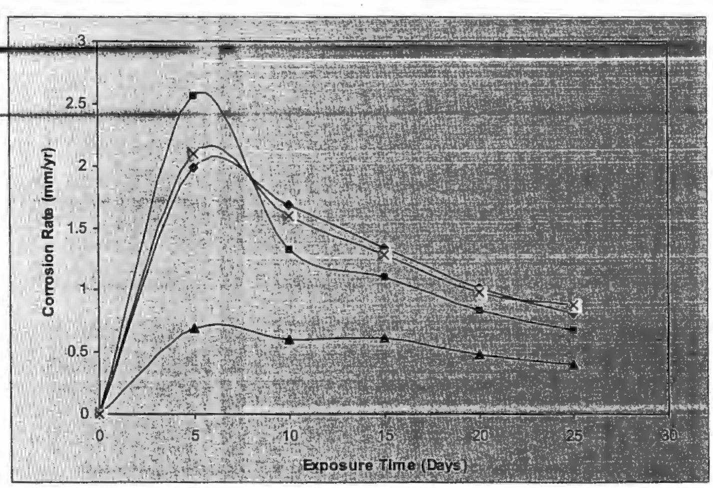


Fig.12. Variation of corrosion rate with exposure time for steel specimen immersed in 0.5M H_2SO_4 and 1ml / 100ml H_2SO_4 addition of the different cashew juices. The key is as in Fig.7.

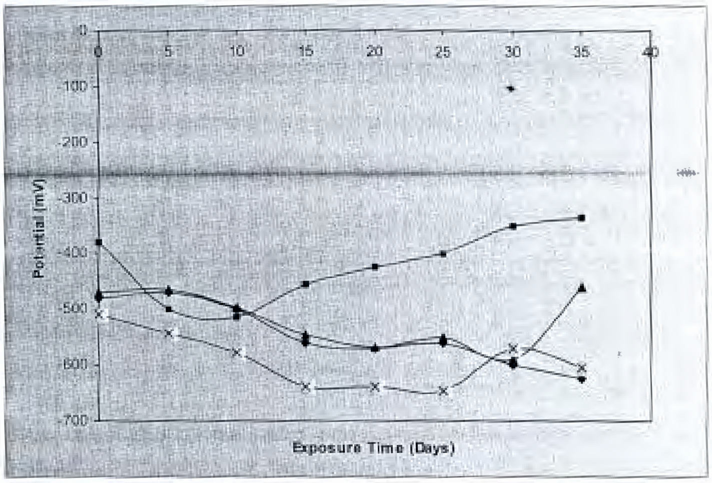


Fig.13. Variation of potential with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew bark juice. The key is as in Fig.1.

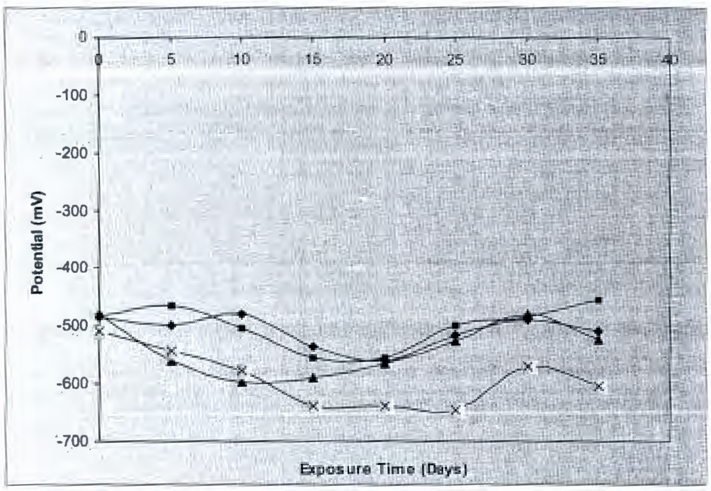


Fig.14. Variation of potential with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew nut juice. The key is as in Fig.1.

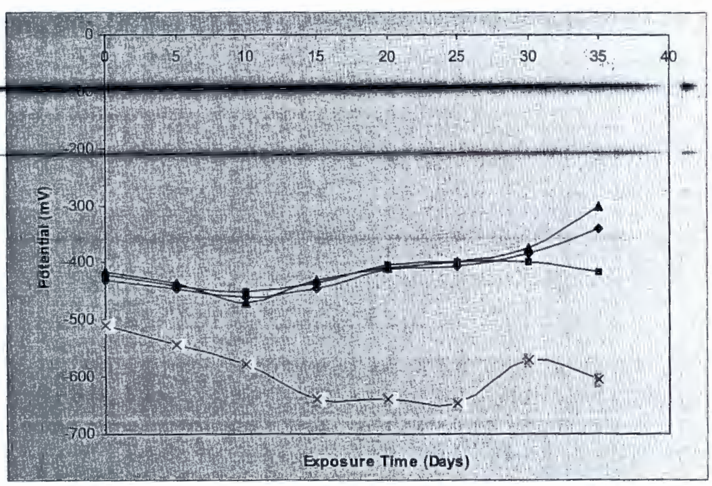


Fig.15. Variation of potential with exposure time for steel specimen immersed in 0.5M H_2SO_4 with varied concentrations of added cashew apple juice. The key is as in Fig.1.

anomalies which are difficult to explain but which may not be unconnected with instrumentation sensitivity and handling.

In Fig.13, the plain acid test (without juice extract addition) gave the highest negative values except in the last five days of the experiment, compared with the curves obtained for the different concentrations of the bark juice extract used as inhibitor in other tests with the acid medium. (In the weight-loss value, only the concentration of 0.5ml bark juice extract/ 100ml H_2SO_4 gave fairly-good corrosion inhibition performance.) This indicates that it was more corrosive for most of the experimental period. However, in Fig.1, the concentrations of 0.2 and 1.0ml bark juice extracts/100ml acid did not perform better than in the plain acid test medium; though the weight-loss values recorded were very close, there tends to be increased corrosion with the addition of these concentrations of bark juice extract. In all cases, the concentration of 0.5ml bark juice extract/100ml acid performed well by giving substantial corrosion inhibition to the steel test specimen. The small deviation from perfect correlation of results observed here might be due to instrumentation sensitivity and handling.

In Fig.14, the nut juice extracts performed better, though not significantly, in corrosion inhibition. These results are in agreement with those obtained in Figs 5 and 6. The reasons for this low corrosion inhibition performance are as explained in the section above.

All the concentrations of 0.2, 0.5, and 1.0ml cashew's apple juice extract/100ml of acid gave a good average performance in all the tests. Except on the last day of the experiment, all the potential values obtained were indeed very close to each other (Fig.15). The results obtained bear a very good correlation with the results for the weight loss and corrosion rate in Figs 3 and 4. The adequate concentration, as indicated by the astringent nature of the apple juice, would have made a contribution to the effective corrosion inhibiting performance of this juice for the test specimen when added to the acid test medium. At 1ml apple juice extract/100ml of acid, a potential of 300mV was achieved on the 35th (the last) day of the experiment. It is, however, not yet certain whether the optimum level of this juice has been used.

continued after *Corrosion cuttings*

Inhibition of cashew juice (*continued from page 20*)

Inhibitor efficiency

The results, obtained by calculation, for the inhibitor efficiency of the various juice extracts used in this work at different concentrations are presented in Table 1. The bark juice extract at a concentration of 0.5ml juice/100ml acid gave an inhibitor efficiency of 51.14%. ; at 0.2ml and 1.0ml/100ml acid, the inhibitor efficiencies were 4.55% and 7.95%, respectively. The optimum level of this juice is therefore, the 0.5ml juice/100ml acid; at this concentration, its effectiveness can be said to be at an average at ambient temperature.

The nut juice extract performed relatively badly, with the highest inhibitor efficiency being 22.73%. The acid nature of this juice must have reduced the potency of tannin, if present, to enhance corrosion inhibition of mild steel test specimen in the acidic test environment. The performance of this juice is very similar at all the various concentrations used.

For the apple juice, the inhibitor efficiency for all the three different concentrations of juice extract is relatively good, on average, at 51.14% at 0.2ml, 50% at 0.5ml, and 54.55% at 1.0ml/100ml acid. This confirms the superiority of the apple juice extract in inhibiting corrosion of mild steel test specimen in the acid when compared to the nut and bark juice extracts.

All the results obtained for the inhibitor efficiency conform, by trend, with those of the weight-loss, corrosion-rate, and potential measurements.

Conclusion

- The bark juice extract at the concentrations used can only inhibit mild steel in 0.5M H_2SO_4 at ambient temperature at a concentration of 0.5ml bark juice extract/100ml of acid.
- The nut juice extract at concentrations of 0.2, 0.5, and 1.0ml/100ml acid provides very low inhibition, with a maximum of 22.73% inhibitor efficiency. This is not significant enough to validate its use.
- A fairly good result is obtained from the apple juice: at all concentrations used, the juice extract gave some measure of corrosion inhibition, with a minimum value of 50% inhibitor efficiency at 0.5ml juice extract/100ml aid. The 0.2ml juice gave 51.14% and the 1.0ml juice /100 ml acid gave 54.55% inhibitor efficiency; this value may be optimized in subsequent studies.

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