The Inhibition Effect of Natural Honey on Corrosion of Stainless Steel in a 17 % HCl Solution

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Abstract Floral, chestnut and acacia honey were tested as corrosion inhibitors via the weight loss method. Weight loss measurements for stainless-steel type AISI 304 dissolution were performed in 17.0 % (wt.) HCl containing different concentrations of added natural honey at room temperature, for 4h, 8h, and 24h immersion periods. These measurements were used to calculate the corrosion rate, and percentage inhibition. The highest inhibition effectiveness for SS AISI 304 was between 80-90 % when the concentration of natural honey was higher than 0.5 % (wt.) for the chosen corrosion system. ATR-FTIR analysis by Fourier-transform infrared analysis was used to confirm the presence of some functional groups in the surface adhered film on the metal surface.

Keywords: corrosion, natural honey, green inhibitor, stainless steel, aggressive medium.

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1 Introduction

Nowadays, too many products in the food chain industry are discarded and treated as waste without giving this a second thought. Before discarding such products, we should take under consideration the possibility of treating those wastes as reusable materials (Girotto *et al.*, 2015).

In general, it is considered that honey does not have an expiration date. Honey is hygroscopic, meaning that it absorbs water molecules from the surface of the material with which it comes into contact, even from the air. This has the effect of providing almost no free water to be used by microbes and mould. Honey also has a low pH value, creating an environment that is usually too acidic for most microbes. In addition, honey naturally produces hydrogen peroxide when it absorbs moisture, which makes it even harder for bacteria to take hold and "spoil" the honey, even if it is improperly stored. However, if the water content of the honey gets high enough, certain types of yeast can survive and ferment the honey somewhat, creating alcohol and in that sense "spoiling" the honey. If honey has a bad or unpleasant taste, there is no need for it to be discarded; it can be used as a corrosion inhibitor, even in a very aggressive medium. On the other hand, natural honey compounds offer interesting possibilities for corrosion inhibition and are of particular interest because of their safe use and high solubility in water. Several studies have shown the inhibition action of natural or mad honey as a promising corrosion inhibitor for some metals and alloys in various media (Pourzarghan, 2017), (El-Etre, *et al.*, 2000), (Radojčić, 2008).

The inhibition behaviour of natural honey in 17.0 (wt.%) aqueous solutions of HCl on the stainless-steel SS type of AISI 304 was studied using the classic gravimetric weight loss technique at room temperature, and for different immersion times (4h, 8h, and 24h). For this purpose, three different types of honey were used (floral, chestnut and acacia honey). The chosen concentrations of added honey were 0.5 %, 1.0 %, 1.5 % and 2.0 % (wt.). Surface analysis of the resulting film on the metal surface was investigated by ATR-FTIR spectroscopy.

2 Experimental

All the gravimetric tests were conducted in 90 ml of aerated solution of 17.0 (wt.%) HCl at room temperature with different concentrations of added honey for 4h, 8h, and 24h immersion periods. The metal surface was abraded successively, using a circulating device under a stream of water and SiC papers of grades 400, 600, 800, 1000, and 1200, washed thoroughly with doubled distilled water, cleaned ultrasonically in a bath of Milli-Q water, rinsed several times with distilled water, and finally dried using hot air.

They were subsequently weighed for the original weight (w_0) and then hung in the test solution with and without the addition of different concentrations of the inhibitor (natural honey) for 4h, 8h, and 24h at room temperature. The corroded specimens were then removed from the solutions, cleaned with distilled water, dried and weighed again to obtain the final weight (w_1). The experimental tests were repeated at least three times, until good reproducibility of the data was achieved.

From the weight loss measurements, the corrosion rate (r) was calculated, using the following equation (1),

$$r = \frac{\Delta w \cdot k}{\rho \cdot A \cdot t}, \tag{1}$$

A – a total area of the stainless-steel specimen
ρ – density of steel
t – the exposure time

where $\Delta w = w_0 - w_1$. (w_0 and w_1 are the specimen weight before and after immersion in the test solution). The corrosion rate was calculated in millimetres per year (mm/yr.). The inhibition efficiency measurements were based on the weight loss at the end of the measurement period. The percentage inhibition efficiency (IE%) was calculated using the equation (2):

$$IE(\%) = \frac{w - w_i}{w} \cdot 100\%, \tag{2}$$

where w and w_1 are the values of corrosion weight loss of stainless steel in uninhibited and inhibited solutions, respectively. FTIR spectra were recorded to understand the interaction of inhibitor molecules (natural honey) with the metal surface (SHIMADZU-IRAffinity-1).

3 Results and discussion

Representative experimental results for weight loss, corrosion rate and inhibition efficiency for SS AISI 304 at 25 °C at different immersion times and different concentrations of three types of honey are given in Table 1. According to Table 1, it is clear that corrosion rate values of SS AISI 304 in a 17.0 (wt.%) solution of HCl decrease when the concentration of added natural honey increases and increase with time of exposure to the HCl solution.

Table 1: Some corrosion parameters for SS AISI 304 in 17.0 (wt.%) HCl from weight loss measurements at different concentrations of added natural honey after 4h, 8h and 24h exposure to the corrosion medium.

17.0 % HCl + 2.0 % of honey									
t (h)	Chestnut honey			Floral honey			Acacia honey		
	Δ*w* (g)	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***
4	0.0036	0.708	85.03	0.0041	0.807	82.95	0.0039	0.767	83.78
8	0.0077	0.758	88.22	0.0072	0.708	88.98	0.0075	0.738	88.52
24	0.0196	0.643	90.73	0.0333	1.092	84.25	0.0290	0.951	86.29

17.0 % HCl + 1.5 % of honey									
t (h)	Chestnut honey			Flower honey			Acacia honey		
	Δ*w* (g)	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***
4	0.0037	0.728	84.62	0.0040	0.787	83.37	0.0043	0.846	82.12
8	0.0087	0.856	86.69	0.0091	0.895	86.53	0.0090	0.886	86.23
24	0.0253	0.830	88.03	0.0395	1.296	85.01	0.0376	1.233	82.22

17.0 % HCl + 1.0 % of honey									
t (h)	Chestnut honey			Floral honey			Acacia honey		
	Δ*w* (g)	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***
4	0.0044	0.866	81.70	0.0046	0.905	80.87	0.0047	0.925	80.46
8	0.0099	0.974	84.85	0.0107	1.053	83.63	0.0108	1.063	83.47
24	0.0332	1.089	84.30	0.0412	1.351	80.52	0.0490	1.607	76.83

17.0 % HCl + 0.5 % of honey									
t (h)	Chestnut honey			Floral honey			Acacia honey		
	Δ*w* (g)	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***	**Δ*w* (g)**	***r* (mm/yr)**	***IE***
4	0.0085	1.673	64.66	0.0117	2.165	51.35	0.0108	2.125	55.09
8	0.0227	2.234	65.26	0.0246	2.460	62.35	0.021	2.066	67.86
24	0.0882	2.893	58.29	0.0937	3.152	55.69	0.1071	3.513	49.35

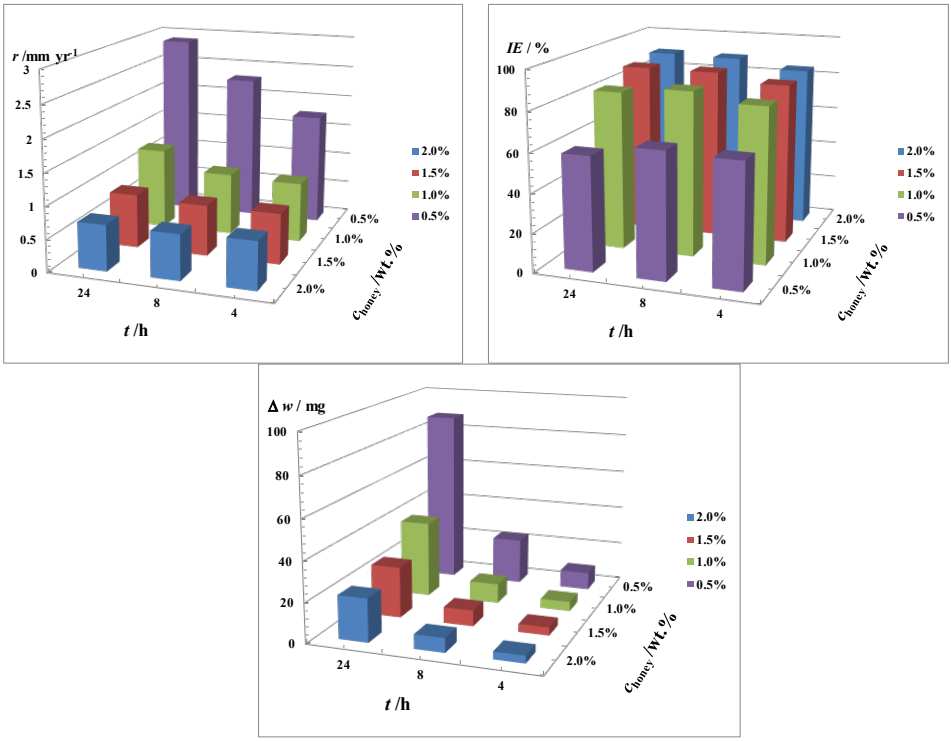

Figure 1: Corrosion parameters: corrosion rate (r), inhibition efficiency (IE%) and weight loss (Δm) for SS AISI 304 from weight loss measurements at different concentrations of added Chestnut honey after 4 h, 8h and 24h exposure to a 17 (wt.%) HCl solution.

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The rapid drop in the corrosion rate as the concentration of added chestnut honey increases from 0.5 % to 1 % (wt.) is shown in Figure 1. The same effect can be observed for the other two types of natural honey (Table. 1).

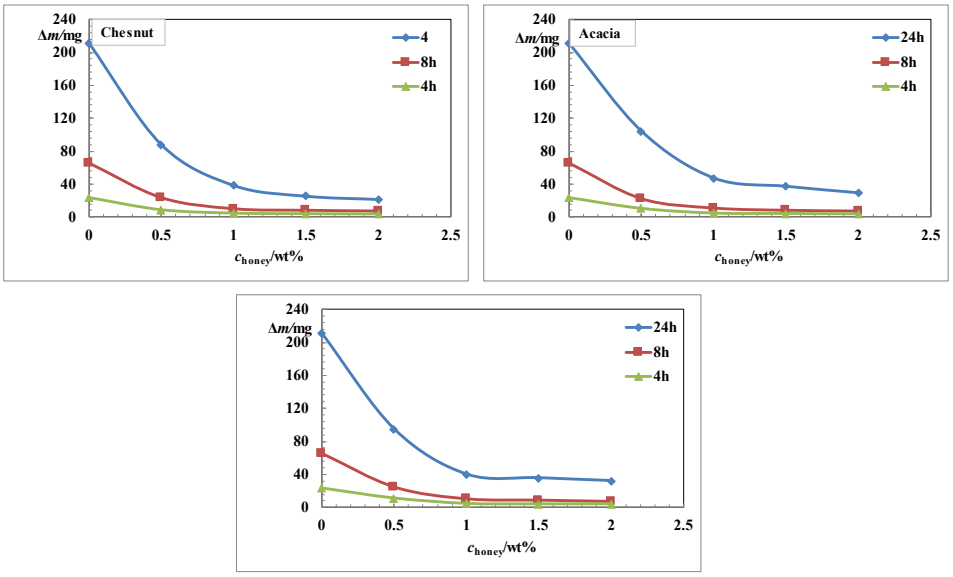

Figure 2: Weight loss against concentration of different types of natural honey for SS AISI 304 after 4h, 8h and 24h exposure to a 17.0 (wt.%) HCl solution.

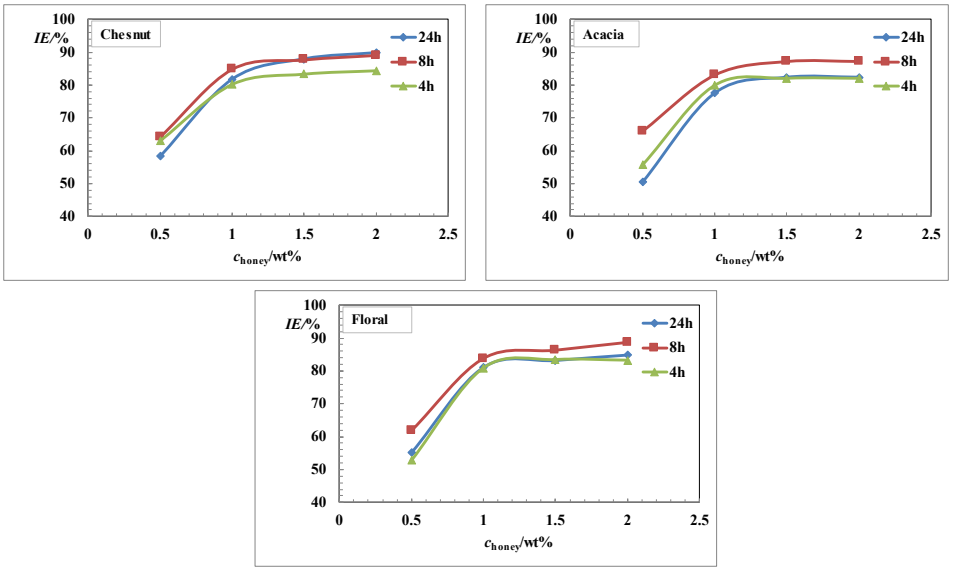

Figure 3: Inhibition efficiency (*IE*%) against concentration of different types of natural honey for SS AISI 304 after 4h, 8h and 24h exposure to a 17.0 (wt.%) HCl solution.

Results clearly show that *IE* increases with increasing concentration of natural honey (inhibitor), while the weight loss decreases. This could be due to the inhibitor molecules acting by adsorption onto the metal surface. When the concentration of all three types of honey is less than 1.0 (wt.%), the *IE* increases sharply with an increase in concentration, while a further increase causes no appreciable change in performance (Figs.2 and 3).

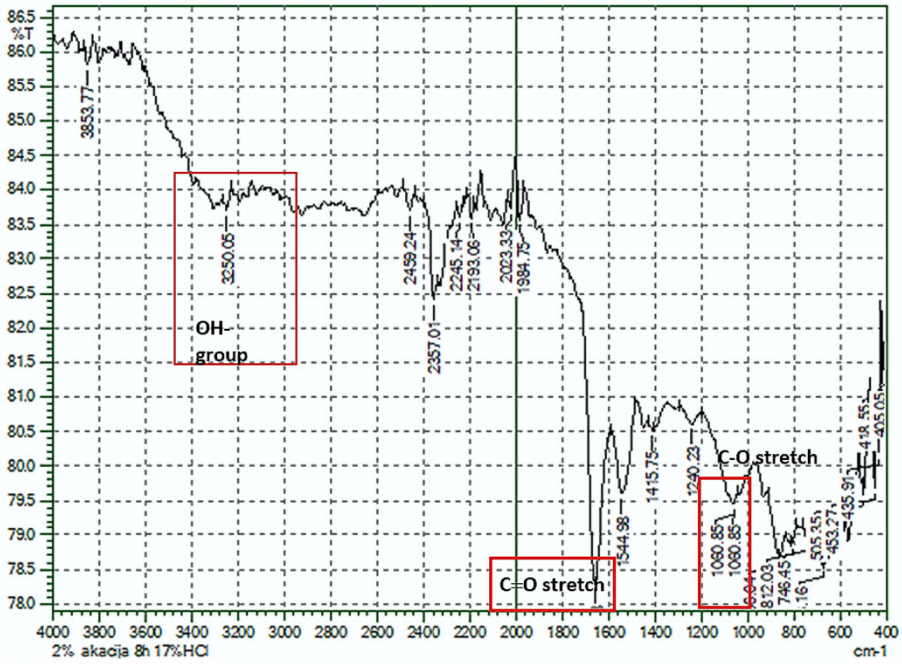

Figure 4: ATR-FTIR absorption spectra of film obtained from the surface of SS AISI 304 after 8h exposure to 17.0 (wt.%) HCl solution in the presence of 2.0 (wt.%) of acacia honey.

It was reported by (Gerengi, 2014) that the constituent molecules of the honey contain oxygen atoms in functional groups (O–H, C–H, C–O, C=O), which meet the general consideration of typical corrosion inhibitors. The adsorption of these compounds on the metal surface reduces the surface area available for the attack of the aggressive ions from the 17.0 (wt.%) HCl solution.

4 Conclusions:

- The results indicated that the introduction of natural honey obviously minimizes the weight loss and abridged SS dissolution in a 17.0 (wt.%) HCl solution.
- The data obtained from the gravimetric method and ATR-FTIR spectroscopy technique confirm that by increasing the concentration of natural honey, the inhibition efficiency on the SS AISI 304 in a 17.0 (wt.%) HCl medium was increased.
- According to the gravimetric studies, natural honey displayed 80-90% corrosion inhibition efficiency on stainless-steel type AISI 304 in a 17.0 (wt.%) HCl medium when the concentration of natural honey was higher than 0.5 % (wt.) for the chosen corrosion system.

Acknowledgments

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