ELECTROCHEMICAL BEHAVIOUR OF ENVIRONMENTALLY-FRIENDLY INHIBITOR OF *ALOE SECUNDIFLORA* EXTRACT IN CORROSION CONTROL OF CARBON STEEL IN SOFT WATER MEDIA

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ABSTRACT

Electrochemical behaviour of Aloe secundiflora *on carbon steel corrosion control in neutral and aerated soft water solutions have been investigated using electrochemical impedance spectroscopy and Tafel polarization techniques. The investigation was performed at different inhibitor concentrations under static and dynamic conditions using a Rotating Disk Electrode (RDE). The impedance and polarization results revealed that* A. Secundiflora *could be a potential corrosion inhibitor for carbon steel undergoing corrosion in fresh water medium. It was found that Aloe secundiflora reduces the electrochemical processes taking place on carbon steel undergoing corrosion. The inhibitor efficiency increases with increase in* A. Secundiflora *concentration and gradually decreases with increase in rotation speed. Optimum inhibitor efficiency of 98% was registered when 200 ppm of* A.Secundiflora *was employed.*

Key words: Corrosion; Corrosion inhibitor; Carbon steel; *Aloe secundiflora*

INTRODUCTION

Corrosion problems arise as a result of metals and alloys reacting electrochemically with corrosive medium to form stable compounds. Problems caused by corrosion attack can be grouped into three categories: health, aesthetic and economics (El-Etre 2008). Internal corrosion in fresh water distribution systems causes considerable consequences for municipalities (Sander *et al*. 1996). The consequences of internal corrosion are pipe breaks, overflow, clogging of pipes with corrosion products and the most serious problem is water quality deterioration which poses health problems to users (Choi *et al*. 2004). Carbon steel pipes have been widely used in fresh water distribution system for decades and for metallurgical strength reasons it is difficult to substitute them with plastic pipes especially when employed from the main pumping stations. Thus, their usage in fresh water industry will still last for some years, and hence research about the corrosion protection of carbon steel is still of great importance (Teng *et al*. 2008). Many researches have been devoted to investigate hundreds of organic and inorganic compounds as inhibitors for carbon steel corrosion in fresh water systems (Li *et al*. 2002). Environmental restrictions imposed on heavy-metal based corrosion inhibitors, have oriented scientific researches towards studying non-toxic and environmentally friendly corrosion inhibitors (Choi *et al* 2002). It should be mentioned here that the first used corrosion inhibitors were naturally occurring substances extracted from various parts of different plants (El-Etre 2008). Besides their safe handling, plant extracts are usually cheap and could be obtained by simple extraction process.

Aloe secundiflora plant has been previously studied to ascertain its bioactivity on newcastle disease and fowl typhoid in local chickens in Tanzania (Waihenya 2002). Research findings do show that the plant possesses profound medicinal elements in the form of anthraquinones, and have been proven to be effective in treating the mentioned diseases (Waihenya 2002). Like other *Aloe* species, *Aloe secundiflora* is extensively grown in semi arid areas, Tanzania mainland being one of the areas where it is grown. In particular, it is cultivated in Same district, in northern Tanzania. The chemical components of *Aloe secundiflora* extract reveal the existence of active groups which suggest a plant to be a potential source of green corrosion inhibitors. The chemical components present include the benzyl pyrone, barbaloin, isobarbaloin, aloinside and isoaloesin, most of them resembling those of some well-known organic corrosion inhibitors (Buchweishaija 1997). Hence, the present study has been done to establish the potential of these active groups in arresting corrosion problem.

EXPERIMENTAL

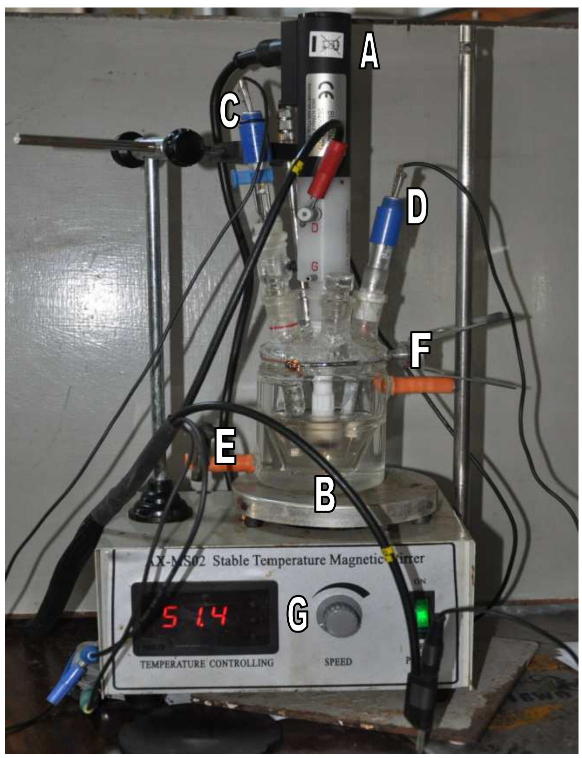
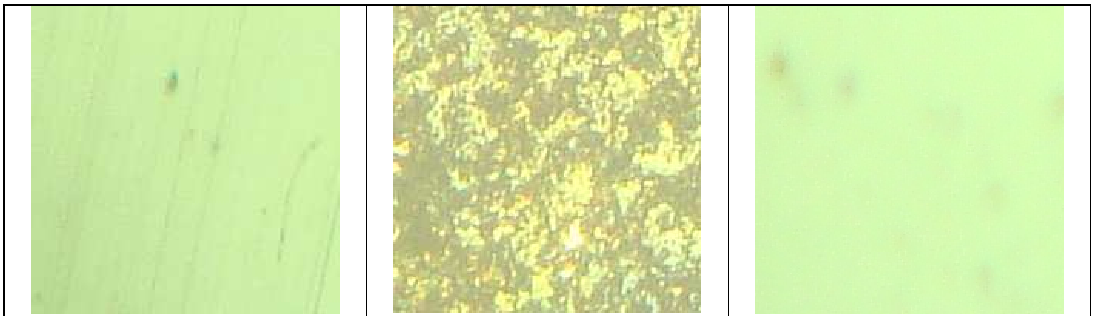


Figure 1: Schematic drawing of the glass cell experimental setup. (A = Rotating Disc Electrode; B = Working Electrode; C = Reference Electrode; D = Counter Electrode; E = Water in; F = Water out; G = Temperature controlling unit

The investigation was carried out in a three electrodes Pyrex glass cell assembly, schematically shown in Fig.1. A Rotating Disk Electrode (RDE) assembly with adjustable speed was used as working electrode. The working electrode was machined from the parent material into disc shaped material exposing the bottom surface area of 0.385 cm^2. The chemical composition of the tested material in weight percentage was 0.172 C, 0.019 Si, 0.433 Mn, 0.210 Cr, 0.014 S, 0.070, 0.038 Co, 0.115 Cu, 0.002 Pb, 0.022 Sn and 98.905 Fe. Prior to electrochemical tests, exposed metal surfaces were wet abraded by SiC paper to 4000 grit, ultrasonic cleaned with acetone and finally rinsed in ethanol before immersion in the test solution. Optical microscope photographs of working electrodes were also taken before and after their immersion in test solutions (Figs. 2 (a), (b) and (c)).



(a) (b) (c)

Figure 2: Optical microscope photographs of the working electrode (ie. carbon steel electrode) at various experimental conditions (a) Freshly polished surface, (b) After immersion in uninhibited test solution for 9 hours, (c) After immersion in inhibited test solution with inhibitor concentration: 200 ppm for 9 hours.

The test solution was fresh water from upper Ruvu water treatment plant. The conductivity of the test solution was improved by adding chloride and sulphate ions (Salasi *et al*. 2007). The pH of the test solution was maintained at 7.0. The corrosion inhibitor used was an extract of *Aloe secundiflora*. The corrosion inhibition process was followed by taking impedance and potentiodynamic polarization measurements. The auxiliary electrode was platinum rod electrode and the potential was measured with respect to Ag/AgCl electrode as a reference electrode.

The impedance measurements were carried out by a computer controlled AutoLab Frequency Response Analyzer (FRA) at open circuit potential with perturbation amplitude of 10 mV vs Ag/AgCl in the frequency range of 10 kHz to 10 mHz at a sweeping rate of 10 points per decade, logarithmic division. At the end of each experiment the potentiodynamic sweeps were conducted starting at the open circuit potential and sweeping typically 200 mV vs Ag/AgCl below and over the open circuit potential. The cathodic and anodic curves were taken separately using a computer controlled AutoLab PGSTAT20 potentiostat. Typical scan rate was 1 mV/sec. The tests were performed in both with and without corrosion inhibitor at different desired experimental conditions. The effects of inhibitor concentrations and rotation speeds were investigated.

RESULTS AND DISCUSSION

It is well established that polarization curves can help to understand how a certain inhibitor works. Inhibitors can modify the anodic process, the cathodic process or both leading to a decreased rate of the corrosion process. The inhibition effect of *Aloe secundiflora* on carbon steel in a mentioned test solution was investigated by polarization technique in both stationary and rotating systems. In all cases the polarization curves were recorded 10 hours after the injection of the *Aloe secundiflora* in the test solution at 30 ^{o}C. Fig. 3 shows polarization curves where the inhibitor was applied in the solution under stationary conditions (0 rpm) while varying the inhibitor concentration; on the other hand, Fig. 4 depicts polarization curves where the inhibitor concentration was maintained at its optimum value of 200 ppm while varying the rotation speed of the RDE.

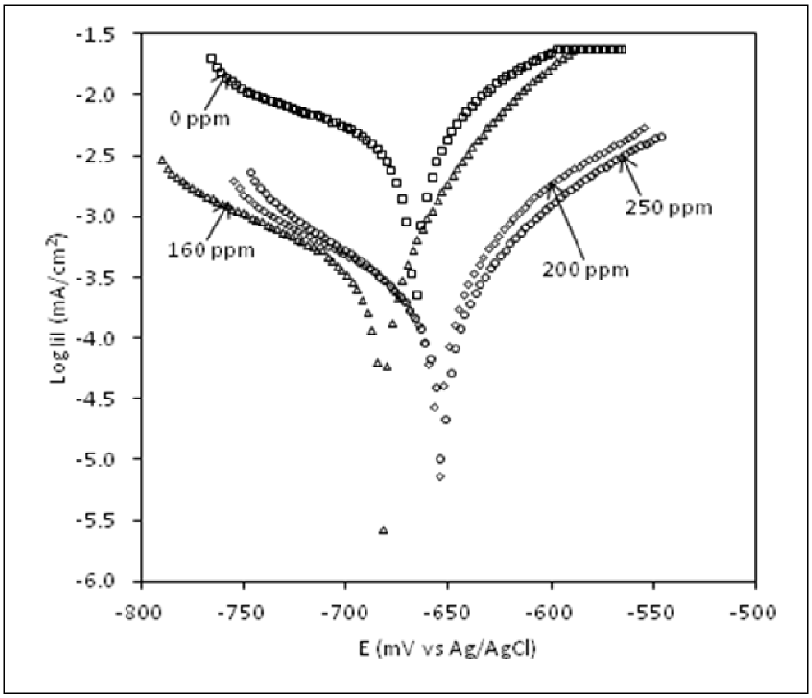


Figure 3: Selected polarization curves showing the performance of *Aloe Secundiflora* at different inhibitor concentrations.

In Fig. 3, two important trends are evident. Firstly that, *Aloe secundiflora* was found to block the electrochemical processes taking place on the steel undergoing corrosion in aerated fresh water medium. It reduces both, rate of cathodic and anodic reactions by reducing the current densities on both sides of the polarization curves in the potential region studied. Secondly, it shifts the open corrosion potentials towards less negative values with reference to the blank, especially for inhibitor concentrations that are close to optimum inhibitor concentration. These factors suggest that the *Aloe secundiflora* inhibitor acts as a mixed type corrosion inhibitor. As for Fig. 4, the trend shows that as the rotation speed increases beyond 2000 rpm, the current densities seem to increase, and the open circuit potentials shift towards more positive value. This suggests that the performance of *Aloe secundiflora* as corrosion inhibitor tends to gradually diminish as the rotation speed increases.

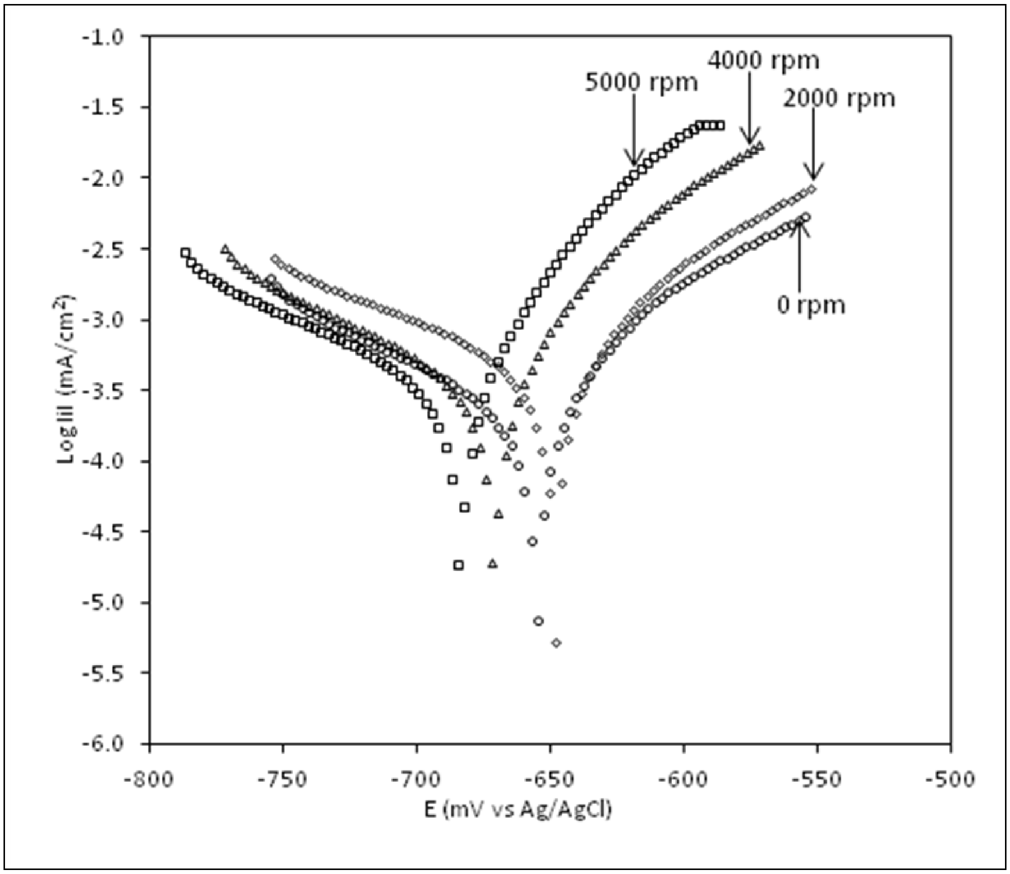


Figure 4: Selected polarization curves showing the performance of *Aloe Secundiflora* at different rotation speeds.

The data obtained from polarization curves by Tafel extrapolations are presented in Tables 1 and 2. The two tables present the values of corrosion potential ($E_{corr.}$), corrosion current density ($i_{corr.}$), and Inhibitor efficiency (IE) for the stationary (0 rpm) and varied *Aloe secundiflora* concentrations, as well as dynamic system operating at a single optimum inhibitor concentration. It can be seen from Table 1 that the corrosion rates decrease significantly at all inhibitor concentrations under stationary condition. Table 1 also gives the Inhibitor Efficiency (IE) for the *Aloe secundiflora*, being calculated from the relation,

$$IE = \left(1 - \left({i_{corr.,i}} / {i_{corr,w}} \right)\right),$$

where $i_{corr.,i}$ and $i_{corr.,w}$ are the corrosion rates with and without inhibitor, respectively. It can be seen that 97 % efficiency is obtained when 200 ppm of *Aloe secundiflora* is applied. Analysed data in Table 2, however, do show the gradual increase in corrosion rate as the rotation speed increases, especially beyond 3000 rpm, resulting into corresponding decrease in Inhibitor Efficiency (IE) of the *Aloe secundiflora*.

Table 1: Electrochemical parameters obtained from polarization measurements on stationary carbon steel electrodes in the presence of different *Aloe Secundiflora* concentrations.

C_{inh} ppm	b_a (mV/dec)	b_c (mV/dec)	E_{corr} (mV vs Ag/AgCl)	i_{corr} (μA cm^{-2})	ν_{corr} (mmpy)	ϕ (%)
0	27	-28	-668	0.99	0.0115	-
40	22	-41	-696	0.34	0.0039	66%
80	19	-30	-685	0.20	0.0023	80%
160	17	-25	-682	0.08	0.0009	92%
200	12	-15	-655	0.03	0.0003	97%
250	15	-15	-654	0.03	0.0003	97%

Table 2: Electrochemical parameters obtained from polarization measurements on rotating mild steel electrodes with different rotation speeds in the presence of 200 ppm of *Aloe Secundiflora.*

Rotation rpm	b_a (mV/dec)	b_c (mV/dec)	E_{corr} (mV vs Ag/AgCl)	i_{corr} (μA cm^{-2})	ν_{corr} (mmpy)	ϕ (%)
0	12	-15	-655	0.03	0.0003	97%
1,000	20	-23	-654	0.07	0.0008	93%
2,000	19	-22	-648	0.08	0.0009	92%
3,000	26	-44	-662	0.09	0.0010	91%
4,000	24	-36	-671	0.11	0.0013	89%
5,000	21	-42	-683	0.12	0.0014	88%

The inhibition process of *Aloe secundiflora* was also studied by electrochemical impedance spectroscopy technique. Impedance measurements in the Nyquist format for carbon steel in fresh water test solution containing different concentrations of *Aloe secundiflora* at stationary and dynamic conditions are shown in Figs. 5 and 6 respectively. Charge transfer resistance and double-layer capacitance values were obtained from impedance measurements as described elsewhere (Philip *et al*. 2001). Table 3 and 4 gives value of charge transfer resistance (R_{ct}), double layer capacitance (C_{dl}) and inhibitor efficiency (IE) obtained from Figs.5 and 6. Since, corrosion rate is inversely proportional to charge transfer Resistance, IE was calculated by use of the relation given above. It is seen from this Table 3 that as *Aloe secundiflora* concentration increases, the R_{ct} values increase while the double-layer capacitance decreases. This indicates that it is corrosion inhibitive in nature. The decrease in the C_{dl} values in the presence of *Aloe secundiflora* show that it adsorbs on the metal surface which results in decrease in double layer. The inhibition efficiencies obtained by impedance studies are in agreement with those obtained employing potentiodynamic polarization technique under stationary condition and varied inhibitor concentration.

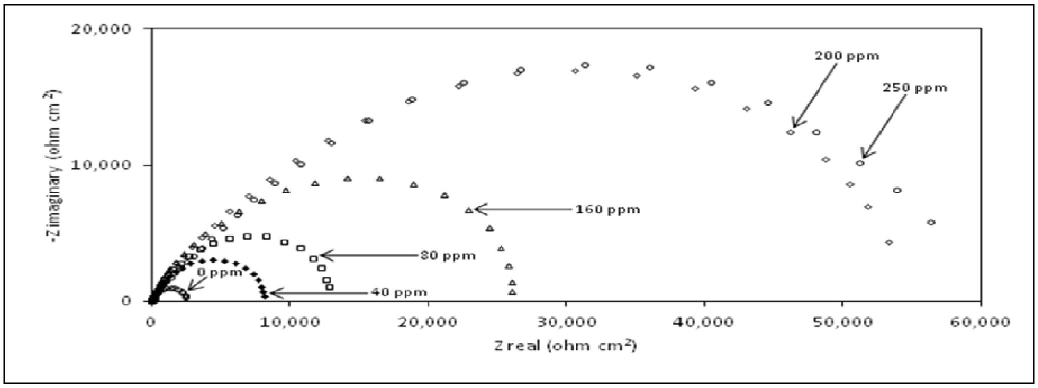


Figure 5: Impedance spectra in Nyquist format showing the performance of *Aloe Secundiflora* at different inhibitor concentrations.

Table 3: Electrochemical parameters obtained from impedance measurements on stationary mild steel electrodes in the presence of different *Aloe Secundiflora* concentrations.

C_{inh} ppm	E_{ocp} (mV vs Ag/AgCl)	R_{ct} (Ω/cm^2)	Q (μF cm^2)	n	C_{dl} (μF cm^2)	i_{corr} (μA cm^{-2})	ν_{corr} (mmpy)	ϕ (%)
0	-664	2,599	164	0.83	654	2.401	0.0278	-
40	-690	8,675	14	0.78	101	0.749	0.0087	69%
80	-683	13,556	11	0.78	80	0.390	0.0045	84%
160	-682	27,349	1.18	0.74	11	0.168	0.0019	93%
200	-656	56,030	0.38	0.70	8	0.054	0.0006	98%
250	-645	56,315	0.35	0.70	7	0.050	0.0006	98%

Table 4: Electrochemical parameters obtained from impedance measurements on rotating mild steel electrodes with different rotation speeds in the presence of 200 ppm of *Aloe Secundiflora.*

Rotation (rpm)	E_{ocp} (mV vs Ag/AgCl)	R_{ct} (Ω/cm^2)	Q (μF cm^2)	n	C_{dl} (μF cm^2)	i_{corr} (μA cm^{-2})	ν_{corr} (mmpy)	ϕ (%)
0	-656	56,030	0.38	0.70	8	0.054	0.0006	98%
1,000	-652	35,750	0.81	0.70	18	0.136	0.0016	94%
2,000	-647	30,180	0.98	0.71	21	0.153	0.0018	94%
3,000	-646	25,235	1.19	0.73	22	0.265	0.0031	89%
4,000	-666	24,463	1.57	0.72	24	0.267	0.0031	89%
5,000	-682	24,375	1.96	0.71	25	0.292	0.0034	88%

An attempt to change the rotation speed during the experiment has also been performed in the inhibited systems after injection of the optimum concentration of *Aloe secundiflora* (i.e. 200 ppm) under dynamic condition at 30 °C. The rotation speeds were varied between 1000 rpm and 5000 rpm and after waiting for a period of 10 hours at each rotation, impedance spectrum was recorded. The impedance results in Nyquist format is shown in Fig. 6. From this figure one would notice that with increased rotation speed the diameter of the semicircle gradually decreases. This indicates that the charge transfer resistance gradually decreases which suggest a gradual decrease in corrosion protection. This also suggests that the inhibitor (*Aloe secundiflora*) film formed is less stable when subjected under high rotation speeds.

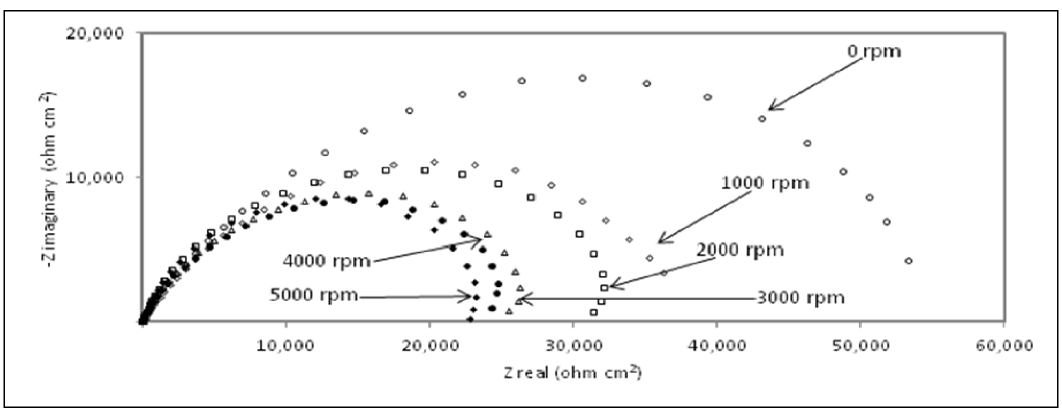


Figure 6: Impedance spectra in Nyquist format showing the performance of 200 ppm *Aloe Secundiflora* at different rotation speeds.

CONCLUSIONS

The main conclusions reported in this paper are as follows:

- The present studies have revealed that *Aloe secundiflora* is an excellent corrosion inhibitor for carbon steel in aerated soft water medium. The *Aloe secundiflora* inhibitor has been found to perform well in both systems, but a better performance was registered under stationary condition. This suggests the tested inhibitor to be the better choice for storage tanks than pipes.

- The results obtained from the polarization measurements indicated that *Aloe secundiflora* is a mixed type inhibitor for carbon steel corrosion in fresh water system, with a significant reduction of current on the anodic reaction.

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