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Seminar: Redactarea lucrărilor științifice: Partea experimentală Rezultate și discuții

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Facultatea de Chimie Industrială și Ingineria Mediului

Laborator: Electrochimie, Coroziune și Inginerie Electrochimică

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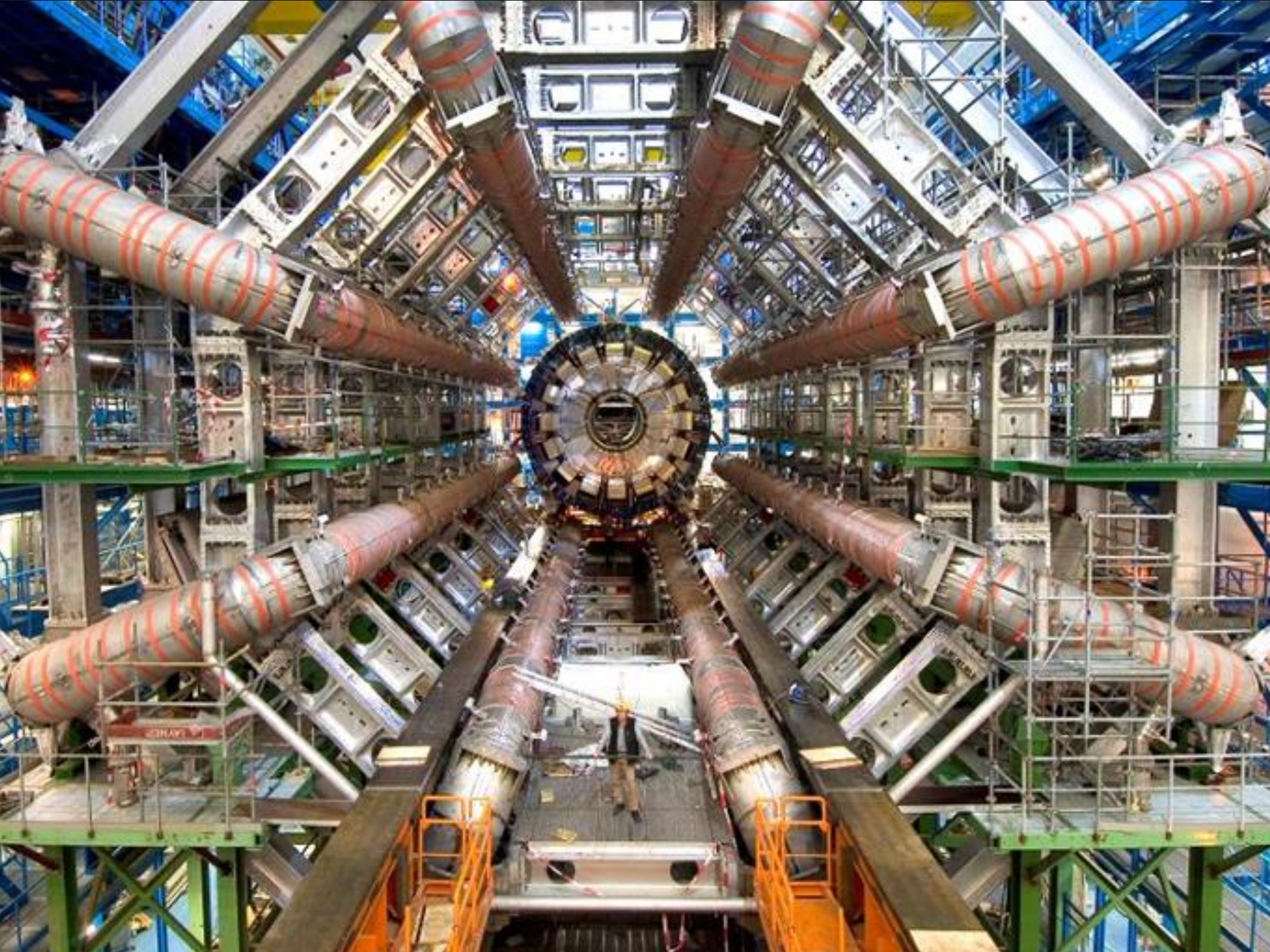
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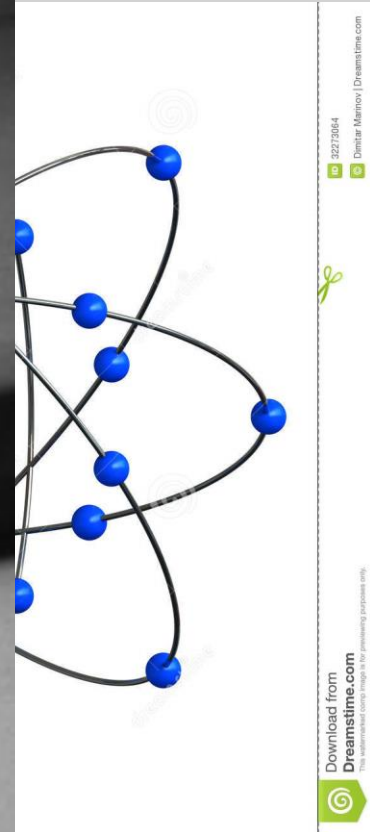
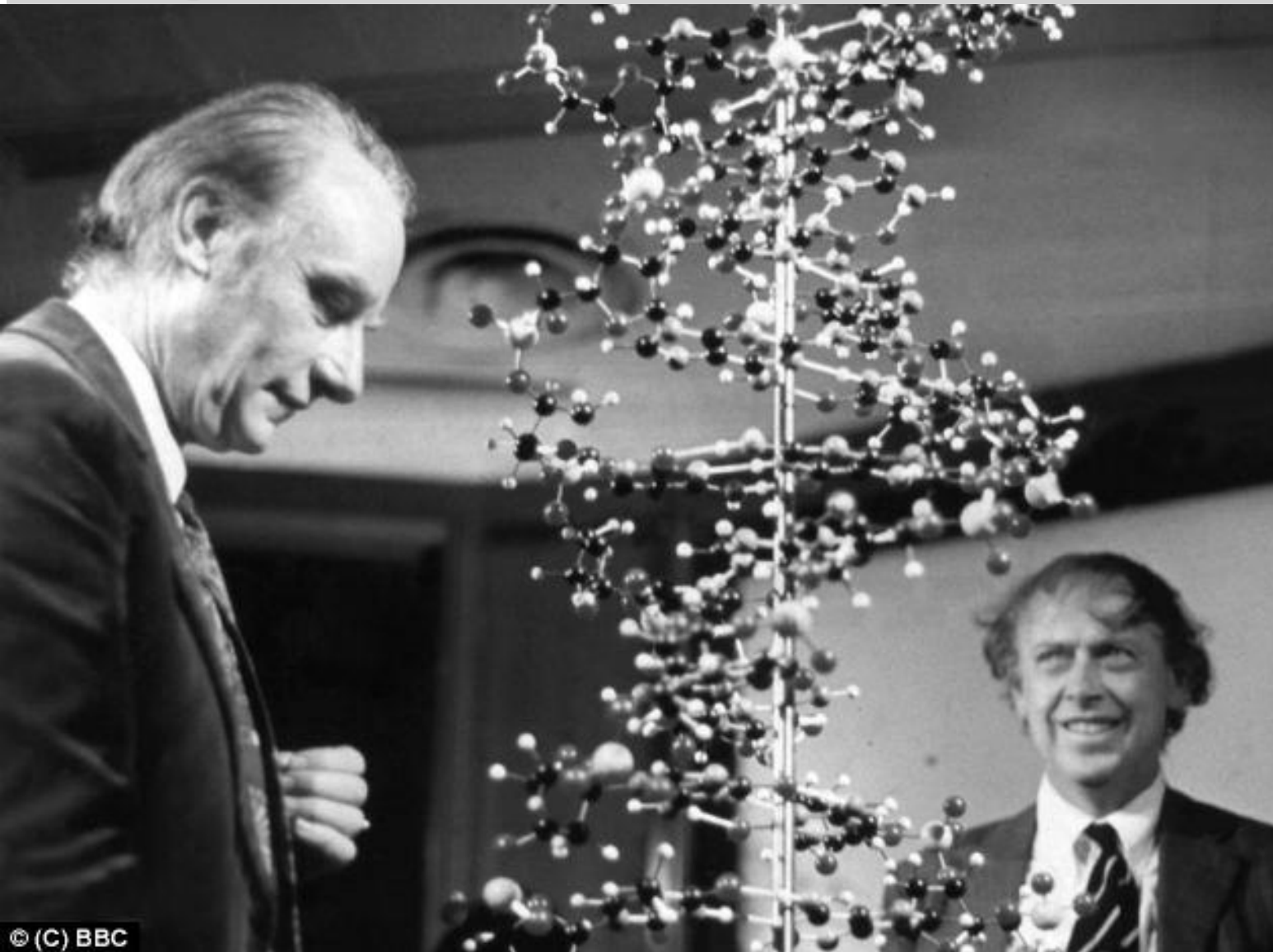
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1. Secțiunea de indexare: titlu, autori, apartenență, istoric, rezumat, cuvinte cheie, bibliografie
2. Secțiunea de conținut: introducere, metode experimentale, rezultate, discuții, concluzii
3. Secțiunea suplimentară: Mențiuni, mulțumiri
4. Secțiune complementară: Anexe

Recent Advancements in Electrode Materials for the High-performance Electrochemical Supercapacitors: A Review

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Supercapacitors are energy storage devices emerging as one of the promising energy storage devices in the future energy technology. In this perspective, rapid progress is made in the development of fundamental and applied aspects of supercapacitors. Various techniques have been developed specifically to estimate the specific capacitance. Numerous efforts were made in the literature to increase the specific capacitance value of the electrode materials. The electrode materials which have unique structural and electrochemical capacitance properties, such as high capacity and cyclic stability showed great supercapacitors performances. Recently, there are much new types of electrode materials were developed to play an important role in the capacitance behavior. In this review, we focused on the applications of various nanostructured electrode materials like carbon nanomaterials, metal oxides and conducting polymer towards highly efficient supercapacitors.

Keywords: Carbon based materials, metal oxides, conducting polymers, supercapacitors



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Semantic Abstraction and Quantum Computation

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Electrochemical supercapacitor application of pervoskite thin films

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Abstract

We have explored electrochemically deposited pervoskite nanocrystalline porous bismuth iron oxide (BiFeO₃) thin film electrode from alkaline bath for electrochemical supercapacitors. The pervoskite BiFeO₃ nanocrystalline thin film electrode showed comparable specific capacitance of 81 F g⁻¹ and electrochemical supercapacitive performance and stability in an aqueous NaOH electrolyte to that of commonly used ruthenium based pervoskites.

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Keywords: Pervoskite thin films; Electrochemical supercapacitor

1. Introduction

A recently invigorated interest in the development of supercapacitor is due to the power requirement of a number of applications that have exceeded the capability of batteries available in the market today [1]. Metal oxides show pseudo-capacitance due to the Faradaic reactions between the solid material and the electrolyte which is voltage dependent. The double layer capacitance has a typical value of 10–40 mF cm⁻² for a real surface, while supercapacitor may be 10–100 times greater. In order to increase the energy and power densities, extensive research on metal oxide electrodes and electrolytes in supercapacitor has been carried out. For the purpose of gaining both high energy and power densities, several types of mixed metal oxides have been proposed as supercapacitor electrodes [2].

Prototypes made of ruthenium oxide have been highly successful and are commercialized [3] due to the idea of using an extra battery is rejected since the modern batteries are incapable of providing high powers without performance degradation. A lot of attempts are going on to increase the capacitance values of the electrode with the

minimum investment. As is highly expensive, alternative metal oxides are being explored. Most of the attempts are made with a small amount of ruthenium which served as an excellent metal oxide for supercapacitor, with other materials for better performance. For example, many researchers have studied the activated carbon with RuO₂ [4,5], where the total specific capacitance of composites as a function of the ruthenium oxide content. Additionally, some researchers have used lead ruthenate pyrochlore, which was able to provide the necessary metal centers for redox reactions [6–8]. One of the attempts to obtain the better performance of supercapacitor electrode was to use pervoskite like SrRuO₃ containing one of element ruthenium [9]. In this work, using the same strategy, the pervoskite BiFeO₃ nanocrystalline electrode is exploited as an efficient potential candidate for supercapacitor application. It is expected that the combined oxide of transition metal oxides, a pervoskite i.e. BiFeO₃ has to show the similar or perhaps better performance. The bismuth iron oxide in five crystallite phases i.e. BiFeO₃, Bi₂Fe₄O₉, Bi₃Fe₅O₁₂, Bi₄Fe₂O₉ and Bi₄Fe₂O₇₂ is well known. That means this material may sustain the charges in its phases during the electrochemical changes.

However, preparation of single-phase BiFeO₃ is a critical task due to its narrow temperature stability range [1]. Moreover, bismuth and iron show the affinity of oxygen

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Cerințe fundamentale la redactare

- CLARITATE
- ADECVARE
- NOUTATE

Structura unei lucrări științifice experimentale:

- Titlu
- Autori
- Apartenența autorilor
- Abstract
- Keywords
- Introduction
- Experimental part (details)
- Results and discussion
- Conclusions
- Acknowledgement
- References

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Orice lucrare științifică trebuie să poată fi verificată de alți cercetători, adică experimentele trebuie să fie reproductibile, fapt care garantează validitatea rezultatelor.

- materialele folosite, indicatori de calitate, furnizori, condiționare și depozitare,
- aspecte teoretice ale metodelor aplicate, formule de calcul, standarde, norme specifice,
- descrierea completă și exactă a echipamentului și a tehnicilor folosite,
- prezentarea în mod exhaustiv a condițiilor de lucru și a operațiilor executate,
- parametri urmăriți experimental,
- modul de prelucrare și interpretare a datelor experimentale, tehnici statistice utilizate,
- informații asupra soft-urilor folosite (licență!!!)

Cerințe:

- prezentarea să fie succintă și clară,
- verbele folosite să fie la timpul trecut!

Results and discussion

Este secțiunea în care sunt anunțate descoperirile autorilor

Sunt prezentate datele obținute de autori sub forma de:

- **tabele,**
- **grafice,**
- **diagrame.**

Se vor evita redundanțele în prezentare.

In mod obligatoriu se includ și rezultatele negative.

**Be sure to include negative results –
writing a results section without them not only invalidate the paper,
but it is extremely bad science.**

Unitati de masura - Sistemul International de Unitati

- Unitati fundamentale

Fundamental Quantities	SI Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of substance	mol	mol
Luminous Intensity	candela	cd

Unitati derivate

Physical Quantity	Symbol	Name and Symbol SI Unit	Fundamental Units Involved	Derived Units involved
frequency	f or ν	hertz (Hz)	s^{-1}	s^{-1}
force	F	newton (N)	$kg\ m\ s^{-2}$	$kg\ m\ s^{-2}$
work	W	joule (J)	$kg\ m^2\ s^{-2}$	Nm
energy	Q, Ep, Ek, Eelas	joule (J)	$kg\ m^2\ s^{-2}$	Nm
power	P	watt (W)	$kg\ m^2\ s^{-3}$	$J\ s^{-1}$
pressure	P	pascal (Pa)	$kg\ m^{-1}\ s^{-2}$	$N\ m^{-2}$
charge	Q	coulomb (C)	A s	A s
potential difference	V	volt (V)	$kg\ m^2\ s^{-3}\ A^{-1}$	$J\ C^{-1}$
resistance	R	ohm (Ω)	$kg\ m^2\ s^{-3}\ A^{-2}$	$V\ A^{-1}$
magnetic field intensity	B	tesla (T)	$kg\ s^{-3}\ A^{-1}$	$NA^{-1}\ m^{-1}$
magnetic flux	Φ	weber (Wb)	$kg\ m^2\ s^{-2}\ A^{-2}$	$T\ m^2$
activity	A	becquerel (Bq)	s^{-1}	s^{-1}
absorbed dose	W/m	gray (Gy)	$m^2\ s^{-2}$	$J\ kg^{-1}$

Figure 103 Derived Units

Prefixe pentru unitati

Prefix	Symbol for Prefix		Scientific Notation
exa	E	1 000 000 000 000 000 000	10^{18}
peta	P	1 000 000 000 000 000	10^{15}
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^9
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deka	da	10	10^1
----	--	1	10^0
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
femto	f	0.000 000 000 000 001	10^{-15}
atto	a	0.000 000 000 000 000 001	10^{-18}

Atentie la prezentarea valorilor numerice: cifre semnificative!!!

$0.3452756489 \text{ V} \rightarrow 0.3453 \text{ V} \rightarrow 0.345 \text{ V}$

$\text{pH} = 7.67895 \rightarrow \text{pH} = 7.68 \rightarrow \text{pH} = 7.7$

$0.000000123 \text{ m} \rightarrow 0.123 \cdot 10^{-6} \text{ m} \rightarrow 1.23 \cdot 10^{-7} \text{ m}$

Prezentarea unitatilor de masura

$$\frac{\text{kg} \cdot \text{m}}{\text{s}^2}$$

$$\text{kg m s}^{-2}$$

Notatii si abrevieri

Temperatura: t T

Energie: E W

Curent: I i

SEM – scanning electronic microscopy;

TEM – transmission electronic microscopy,

DNA – deoxiribinucleic acid,

NMR – nuclear magnetic resonance



Corrosion resistance of carbon steel in weak acid solutions in the of L-histidine as corrosion inhibitor

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Inhibition efficiency
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ABSTRACT

This paper presents the inhibitory properties of L-histidine on the corrosion media containing acetic acid/sodium acetate. The inhibition efficiencies are in good agreement with values given by Tafel method a spectroscopy. The adsorption of L-histidine obeys the Langmuir isotherm a energy indicate the nature of interactions between inhibitor molecules : inhibition effect was studied using scanning electron microscopy and em

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1. Introduction

The use of chemical compounds in a very wide range of applications is restricted by the protection of the environment and health considerations. Lately, at industrial level, it was required to use chemicals not only due to their efficiency, but also to their safety. These concepts are valid as well in the field of organic compounds which act as corrosion inhibitors for metals and alloys. In this respect, there is a special emphasis on natural compounds, nontoxic and ecologically friendly. In this way, berberine [1], tryptamine [2] and some extracts from natural plants [3–6] were reported as efficient corrosion inhibitors for steel and iron in different test solutions. The amino acids and derivatives have been used as good corrosion inhibitors for mild steel [7–12], carbon steel [13–15], stainless steel [16], iron [17], nickel [18], copper [19,20], aluminum [21], and alloys [22,23] in different aggressive solutions.

Generally, these compounds act on the corrosion process by adsorption on the metal surface, forming a protective film and blocking the active sites. The adsorption mechanism of the inhibitor molecules plays a very important role because the protection degree of the metal or alloy depends on the adsorption process [16].

The aim of this work is to investigate the inhibiting properties of L-histidine on the corrosion process of carbon steel in corrosive solutions containing sodium acetate, the main ingredient used in deicing solutions [24], and acetic acid in order to ensure a constant pH and more aggressive media. Sodium acetate, either liquid or solid, is effective at low temperature in ice and deep snow [24], and

has been used on some winter roadways, being less corrosive and more suitable [25]. Ice Shear is an improved deicing sodium acetate and sodium formate which exerts freezing point of water, penetrates ice bonding between the ice and pavement deicers with an ecological corrosion inhibition taking into account that this kind of salt e.g. highways, airplanes and airports, etc.

Studies on the corrosion process of solutions are of industrial importance. A boxyl group makes them a basic building blocks such as drugs, pharmaceuticals.

It is required to mention that L-histidine corrosion inhibitor for mild steel as well as alloys [7].

2. Experimental

The weight loss, linear polarization, spectroscopy and cyclic voltammetry were used to observe the inhibitive properties of process. The surface morphology of the studied and discussed.

2.1. Materials

The chemical structure of L-histidine

Table 1
Elemental composition of the carbon steel samples.

Element	Fe	C	Si	Mn	P	S	Cr	Ni
wt.%	96.98	0.4184	0.2510	0.7920	0.0132	0.0335	1.162	0.029
Element	Mo	Cu	Al	Ti	V	Co	Nb	W
wt.%	0.2123	0.0234	0.0229	<0.004	0.0124	0.0222	<0.001	<0.010

Experimental measurements were carried out on cylindrical samples of carbon steel with the elemental composition presented in Table 1.

Different concentrations of the inhibitor, L-histidine (Merck, 99%), between 10^{-4} and 10^{-2} M, have been used to determine the inhibition effect of this amino acid on the corrosion rate of carbon steel in 0.5 M $\text{CH}_3\text{COOH}/0.25$ M CH_3COONa test solutions. The corrosive media was prepared from glacial acetic acid (Fluka, 99.8%) and sodium acetate (Fluka, 99%).

2.2. Weight loss measurements

Weight loss (W) experiments were carried out using disc samples of carbon steel having the dimensions Φ 15 mm $\times$ 5 mm. Before immersion in the test solutions with or without the inhibitor, the samples were abraded with different SiC paper (220, 500, 800, and 1000), ultrasonically cleaned in distilled water, rinsed with acetone and finally dried. After 240 h exposure time at room temperature in 100 mL corrosive solutions, the specimens were taken out, brushed under running water to remove the corrosion products, washed with distilled water and acetone and dried. Before and after the corrosive attack the samples have been weighed using an analytical balance (precision ± 0.1 mg). The weight loss in $\text{mg cm}^{-2} \text{h}^{-1}$ has been calculated using Eq. (1) [29]:

$$W = \frac{W_1 - W_2}{S \times t} \quad (1)$$

where W_1 and W_2 are the initial and final mass of the samples in mg, S is the total surface area of specimens in cm^2 and t is the exposure time in h.

From the calculated W the inhibition efficiency (η) and surface coverage (θ) of the inhibitor were obtained using Eqs. (2) and (3) [30]:

$$\eta(\%) = \left(1 - \frac{W_{\text{corr}}}{W_{\text{corr}}^0}\right) \times 100 \quad (2)$$

$$\theta = 1 - \frac{W_{\text{corr}}}{W_{\text{corr}}^0} \quad (3)$$

where W_{corr} and W_{corr}^0 are the weight loss of the samples in the presence and absence of the inhibitor, respectively.

2.3. Electrochemical measurements

Potentiodynamic polarization measurements were carried out in 0.5 M $\text{CH}_3\text{COOH}/0.25$ M CH_3COONa test solutions in the absence

and presence of different concentrations (10^{-4} – 10^{-2} M) of L-histidine, in a conventional three-electrodes cell at room temperature. Carbon steel samples with 1 cm^2 surface area in contact with solution were used as working electrodes, the reference was a silver-silver chloride electrode ($\text{Ag}/\text{AgCl}/\text{saturated KCl}$) and two graphite rods were used as counter electrodes. The samples preparation before the experiments was similar to weight loss measurements. Before each experiment the test solutions were deaerated by bubbling high purity nitrogen in order to avoid any reaction with dissolved oxygen. Polarization curves were obtained with an Autolab PGSTAT 302N at a scan rate of 2 mV s^{-1} in the potential range of -200 mV to $+200 \text{ mV}$ relative to the open circuit potential. Electrochemical impedance spectroscopy (EIS) measurements were carried out at E_{corr} , at $298 \pm 1 \text{ K}$ after a stationary state was achieved in the frequency range from 10 kHz to 10 mHz and AC voltage amplitude of 10 mV peak to peak. The EIS spectra were measured in a three electrodes cell connected to a PAR 2263 potentiostat. The working electrode was carbon steel with an active surface of 0.5 cm^2 , the counter electrode was a Pt wire and the reference was a saturated calomel electrode. Before each experiment the surface of the electrode was prepared similarly as previously described and the test solutions were deaerated by bubbling pure nitrogen for 1 h.

2.4. Surface morphology

Carbon steel surface was analyzed with a Keyence VHX-600 Digital Microscope and a Philips XL 30 ESEM scanning electron microscope (SEM), respectively. The images of the samples, same used in the weight loss measurements, were recorded after 240 h exposure time in test solutions in the absence and the presence of L-histidine.

3. Results and discussion

3.1. Weight loss data

From the weight loss data of carbon steel samples after 240 h immersion time in corrosive solutions, in the absence and presence of different amounts of L-histidine, the inhibition efficiency and surface coverage were calculated and the results are given in Table 2. The results indicate that amino acid reduces the corrosion process and the effect is more pronounced as the concentration of the inhibitor increases.

Table 2
The inhibition efficiency and surface coverage obtained by weight loss measurements.

L-histidine conc. (M)	η (%)	θ (surface coverage)
1×10^{-4}	31.9	0.319
5×10^{-4}	44.5	0.445
1×10^{-3}	58.2	0.582
5×10^{-3}	68.7	0.687
1×10^{-2}	81.6	0.816

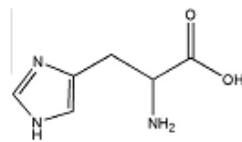


Fig. 1. Chemical structure of L-histidine.

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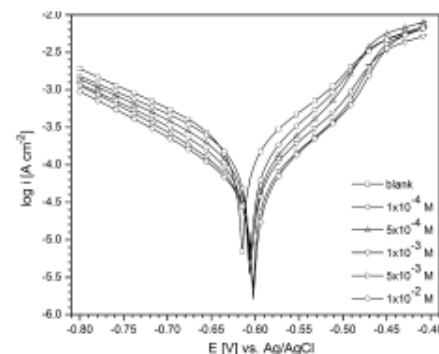


Fig. 2. Linear polarization curves on carbon steel electrode in 0.5 M CH₃COOH/0.25 M CH₃COONa with and without various concentrations of L-histidine.

3.2. Linear polarization

One of the most used methods to determine the corrosion rate of metals and alloys in corrosive solutions is linear polarization. Fig. 2 reveals the cathodic and anodic polarization curves obtained for carbon steel in 0.5 M CH₃COOH/0.25 M CH₃COONa at room temperature in the absence and presence of different concentrations of L-histidine.

The values of electrochemical parameters associated with this process, i.e. corrosion potential (E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c and b_a) and corrosion rate were determined by extrapolating potentiodynamic curves using GPES software. Also, the inhibition efficiency (η) and surface coverage have been calculated with Eqs. (4) and (5) [31] and the values obtained are presented in Table 3.

$$\eta(\%) = \left(\frac{i_{corr} - i_{corr}^0}{i_{corr}^0} \right) \times 100 \quad (4)$$

$$\theta = \frac{i_{corr} - i_{corr}^0}{i_{corr}^0} \quad (5)$$

where i_{corr} and i_{corr}^0 are the uninhibited and inhibited corrosion current densities, respectively.

The analysis of data given in Table 3 shows that both the cathodic and anodic Tafel slopes decrease indicating that L-histidine is a mixed type inhibitor acting on both the hydrogen evolution reaction and metal dissolution. Moreover, the Tafel slopes do not suffer significant variation with increase of amino acid concentration suggesting that the presence of inhibitor in the test solution does not modify the process mechanism and act as adsorptive inhibitor, retarding both cathodic and anodic reaction by blocking the active sites [17,32]. An increase in inhibitor concentration probably

increase the number of inhibitor interface and decrease the corrosion potential value slightly. The inhibition process can be attributed to L-histidine molecules on the active sites of corrosion products on the metal surface.

From the Tafel polarization resistance inhibition mechanism involves blocking the active sites of corrosion products on the metal surface by the inhibitor molecules via adsorption.

3.3. EIS measurements

Information about the inhibition mechanism also obtained by electrochemical impedance spectroscopy (EIS). The advantage of this method is that it does not require the measurement of the corrosion current density, which is usually replaced by a whole impedance given by:

Fig. 3 gives the EIS spectra of carbon steel with and without various concentrations of L-histidine. The complex plane plots reveal a depressed semicircle. The diameter of the semicircle represents the polarization resistance and its value is usually replaced by a whole impedance given by:

A simple electrical equivalent circuit (EIS) to model the experimental data, consisting of the solution resistance (R_s) in series with the parallel combination of the double layer capacitance (C_{dl}) and the charge transfer resistance (R_{ct}). Due to the deviations from a perfect semicircle, the constant phase element (CPE) is usually replaced by a whole impedance given by:

$$Z_{CPE} = 1/T(j\omega)^n$$

where T is a parameter related to the CPE, which is an exponent between 0 and 1 due to the non-ideal behavior of the CPE.

The experimental data were fitted by linear least-squares (NLS) procedures of the circuit elements are given standard errors.

The inhibition efficiency was calculated using Eq. (7) [31]:

$$\eta(\%) = \left(\frac{R_{p,inh} - R_p}{R_{p,inh}} \right) \times 100$$

where $R_{p,inh}$ and R_p are polarization resistances in the absence and presence of L-histidine.

The obtained values of the inhibition efficiency and the values calculated from linear weight loss measurements.

Double layer capacitance value was calculated using Eq. (8) and

$$T = C_{dl}^n (R_s^{-1} + R_p^{-1})^{1-n}$$

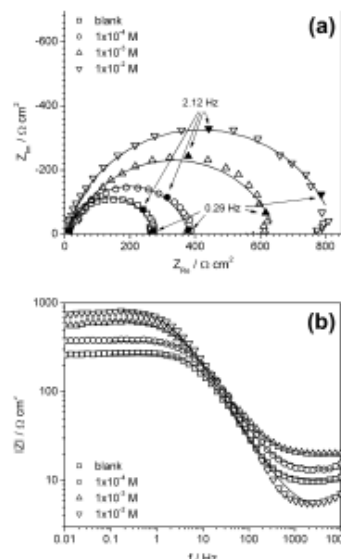


Fig. 3. Experimental Nyquist (a) and Bode (b) plots of carbon steel in 0.5 M CH₃COOH/0.25 M CH₃COONa with and without various concentrations of L-histidine. Symbols are experimental data and continuous lines are obtained by NLS fitting.

It can be observed that the double layer capacitance in the absence of inhibitor is larger than in its presence. The addition of L-histidine in the test solution leads to a decrease of the double layer capacitance, because the inhibitor molecules adsorb at the inner Helmholtz plane and block the active sites on the metal surface.

3.4. Cyclic voltammetry

The manner in which L-histidine can influence the corrosion process is pointed by its electrochemical behavior in test solutions studied by cyclic voltammetry. Fig. 4 shows the cyclic voltammograms recorded in 0.5 M CH₃COOH/0.25 M CH₃COONa on platinum electrode in the absence and the presence of different amounts of inhibitor. On the base curve, in the absence of L-histidine, the anodic branch corresponding to the oxygen release (curve 1) and the cathodic one for hydrogen evolution reaction (curve 2) are distinctive. Further, one can also observe the reduction peak (3) of the oxide layer formed on electrode surface and the peak (4) associated with the oxidation of adsorbed hydrogen. The addition of compound in the test solution leads to an increase of the current (5) that can be attributed to amino acid oxidation. Also, the presence of inhibitor in the test solution reduces the cathodic and anodic processes.

The cyclic voltammograms measured on carbon steel electrode in the same test solutions in the absence and the presence of L-histidine are presented in Fig. 5. The main curve shows, along the oxygen and hydrogen evolution reactions (2 and 6), the characteristic peaks for metal dissolution (1 and 4). On the cathodic branch, one can observe the reduction current (peak 3) corresponding to the reduction of the passive film and the current plateau 5 attributed to the reduction of iron ions to metallic iron. Also, in the anodic sense, peak 7, corresponding to the oxidation of adsorbed hydrogen on metal surface, is observed.

In the presence of the amino acid in the test solution, the passivation of the metal surface occurs more easily, critical current being reduced.

3.5. Adsorption isotherm

Useful information about the inhibition mechanism of carbon steel corrosion process can be gained from adsorption isotherm, by determining the standard Gibbs free energy value that characterizes the type of interaction existing between inhibitor molecules and metal surface. The Gibbs energy was calculated with Eq. (9) [35].

$$\Delta G_{ads}^0 = -RT \ln(55.5 K_{ads}) \quad (9)$$

where R is the universal gas constant 8.314 J mol⁻¹ K⁻¹, T the thermodynamic temperature in K, K_{ads} is the equilibrium constant for the adsorption process and 55.5 represents the molar concentration of water in the solution.

In the case of amino acids adsorption the most suitable isotherm was found to be Langmuir isotherm, written in the linear form (10) [10,11,23]:

$$\frac{C_{inh}}{\theta} = \frac{1}{K_{ads}} + C_{inh} \quad (10)$$

From the linear dependence $C_{inh}/\theta = f(C_{inh})$ drawn using the experimental parameters computed from weight loss data and Tafel slopes (Fig. 6), the value of the adsorption constant was calculated. The regression coefficient R^2 for all methods was very close to 1, indicating that the adsorption process of L-histidine on metal surface obeys the Langmuir isotherm. The values of standard Gibbs free energy determined by the three methods are -28.7 kJ mol⁻¹ by Tafel slopes, -28.5 kJ mol⁻¹ by weight loss data and -30.8 kJ mol⁻¹ by EIS measurements, revealing that the adsorption of inhibitor molecules on metal surface takes place due to electrostatic interactions between the amino acid molecules and electrode surface. Generally, values of the free energy less negative than -40 kJ mol⁻¹ are associated with processes that occur by physical adsorption of the inhibitor on metal surface [36].

It is noted that the mechanism of corrosion inhibition of carbon steel in 0.5 M CH₃COOH/0.25 M CH₃COONa solution in the presence of L-histidine can be deduced on the basis of adsorption isotherms. It is well known that in an acid solution L-histidine exists as a protonated species like some other amino acids [17,20,21]. For acetic acid/sodium acetate the calculated value of pH is 4.46 and the protonation degree of the inhibitor is very close to 1, taking into account the following reaction equilibrium equations:

Table 3
Polarization parameters for the corrosion of carbon steel in 0.5 M CH₃COOH/0.25 M CH₃COONa with/without various concentration of L-histidine.

Inh. conc. (M)	i_{corr} (μA cm ⁻²)	$-E_{corr}$ (mV)	$-b_c$ (mV dec ⁻¹)	b_a (mV dec ⁻¹)	R_p (Ω)	Corr. i
Blank	159.0	615	168	118	44.3	1.87
1 × 10 ⁻⁴	114.1	605	165	102	64.1	1.34
5 × 10 ⁻⁴	89.3	605	155	102	76.1	1.05
1 × 10 ⁻³	70.1	605	152	102	96.5	0.82
5 × 10 ⁻³	52.2	603	142	95	121.8	0.61
1 × 10 ⁻²	33.1	601	141	87	148.7	0.48

Table 4
Experimental values of EEC parameters for carbon steel in 0.5 M CH₃COOH/0.25 M CH₃COONa solution with/without various concentration of L-histidine.

Inh. conc. (M)	R_p (Ω)	T (F cm ⁻² s ⁿ⁻¹)	n	R_p (Ω cm ²)	C_{dl} (μF cm ⁻²)	η (%)
Blank	9.3 (1.5%)	1.16 × 10 ⁻⁶ (3.9%)	0.90 (0.7%)	264 (1.1%)	54.6	-
1 × 10 ⁻⁴	12.5 (1.7%)	1.14 × 10 ⁻⁶ (4.0%)	0.85 (0.8%)	375 (1.3%)	35.7	29.6
1 × 10 ⁻³	18.8 (1.0%)	1.64 × 10 ⁻⁶ (2.2%)	0.80 (0.5%)	642 (1.0%)	38.4	58.9
1 × 10 ⁻²	4.5 (5.6%)	1.39 × 10 ⁻⁶ (2.5%)	0.85 (fixed)	828 (3.8%)	37.8	68.1

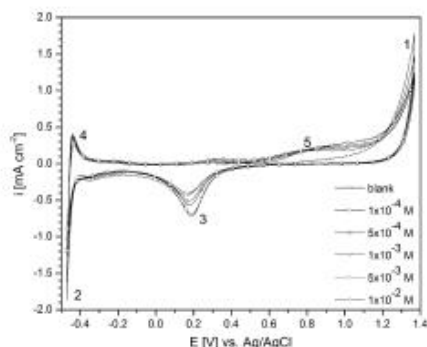


Fig. 4. Cyclic voltammograms on Pt electrode in 0.5 M CH₃COOH/0.25 M in the absence/presence of L-histidine, scan rate 50 mV s⁻¹.

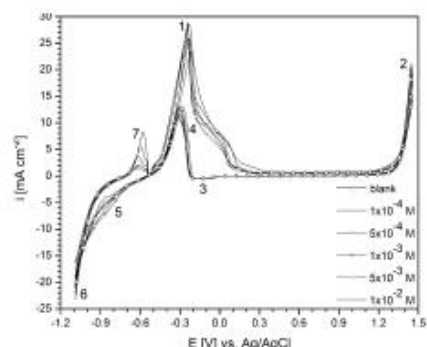


Fig. 5. Cyclic voltammograms on carbon steel electrode in 0.5 M CH₃COOH/0.25 M in the absence/presence of L-histidine, scan rate 50 mV s⁻¹.

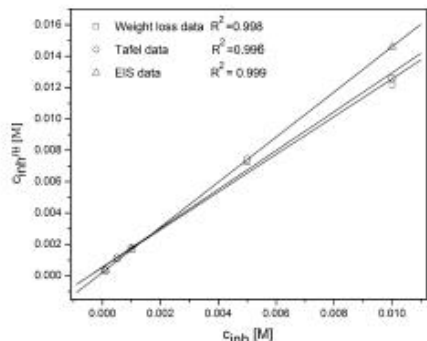
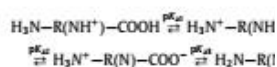


Fig. 6. Langmuir adsorption isotherm for L-histidine obtained by weight loss, EIS and Tafel data.



The values of acidity constants are $\text{p}K_{\text{a}1} = 9.08$ [37]. As a consequence, in almost all amino acid molecule ($\text{H}_3\text{N}^+-\text{R}(\text{NH}^+)-\text{COO}^-$). Due to the electrophilic carbon steel and inhibitor molecules, on the cathodic active sites of metal evolution reaction. At the same time molecules can adsorb on the steel surface nitrogen atoms of imidazole ring or unshared electron pairs.

3.6. Surface analysis

The surface morphology of the carbon steel after corrosive attack by the media in the absence and presence of L-histidine has been performed after the products formed on the sample surface of L-histidine the surface of the sample (Fig. 7a), while the presence of His favours a compact layer that protects the sample.



Fig. 7. Microscope images after removing the (b) with 10⁻² M L-histidine.

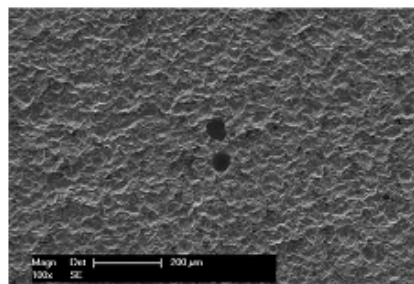
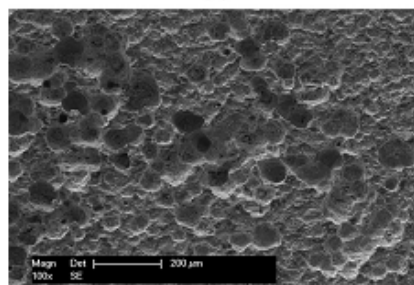
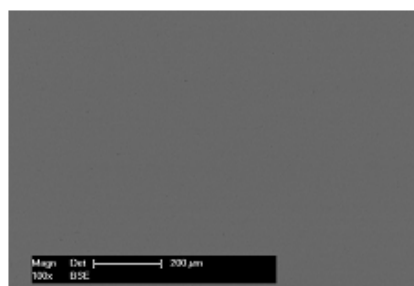


Fig. 8. SEM images obtained for carbon steel samples: abraded without immersion in test solutions (a); after 240 h immersion in the blank solution (b); and after 240 h immersion in the test solution with 10⁻² M L-histidine (c).

Details about surface morphology were obtained by scanning electron microscopy.

Fig. 8 shows the SEM images recorded for the abraded surface of the carbon steel sample (a) and after removing the oxide layer from the surface. In the absence of inhibitor the image reveals clear pits and cavities with roughness due to metal dissolution under corrosive attack by the media (b). For 10⁻² M concentration of inhibitor there are fewer corrosion marks observed on sample (c), suggesting that the carbon steel surface was protected by L-histidine molecules.

The atomic percentage of the elements is shown in Table 5.

Table 5
Atomic percentage of the elements.

	Fe	C	Cr	Si	Al	Mo	O
Blank	74.17	22.45	1.5	1.38	–	–	–
10 ⁻² M inh.	45.77	38.94	1.6	4.85	1.35	1.56	5.93

4. Conclusions

L-histidine is a mixed safe corrosion inhibitor for carbon steel in weak acid solutions that acts both over the cathodic process of hydrogen evolution and the anodic process of metal dissolution. Inhibition efficiency was determined by three different methods: weight loss, linear polarization and electrochemical impedance, all giving comparable results. Inhibition efficiency increases with the amount of inhibitor and the maximum value was 81.6% for 10⁻² M L-histidine. The amino acid adsorption on metal surface obeys Langmuir isotherm, and the value of Gibbs free energy reveals the electrostatic interactions between the charged molecules and the charged carbon steel. Generally, values of the free energy less negative than -40 kJ mol^{-1} are associated with processes that occur by physical adsorption of the inhibitor on metal surface. From surface analysis it results that amino acid suppresses the corrosion process by forming a protective film over the metal surface which prevents penetration of the corrosive media. The double layer capacitance obtained from EIS measurements decreases with the increasing of inhibitor concentration, arguing an adsorption process of the L-histidine on the metal surface.

The good inhibition efficiencies of L-histidine in acetic acid/sodium acetate solution makes it a suitable alternative as environmentally friendly corrosion inhibitor in deicing solutions in which sodium acetate is a main component. The advantages of this inhibitor consist in biodegradability and zero impact on the environment.

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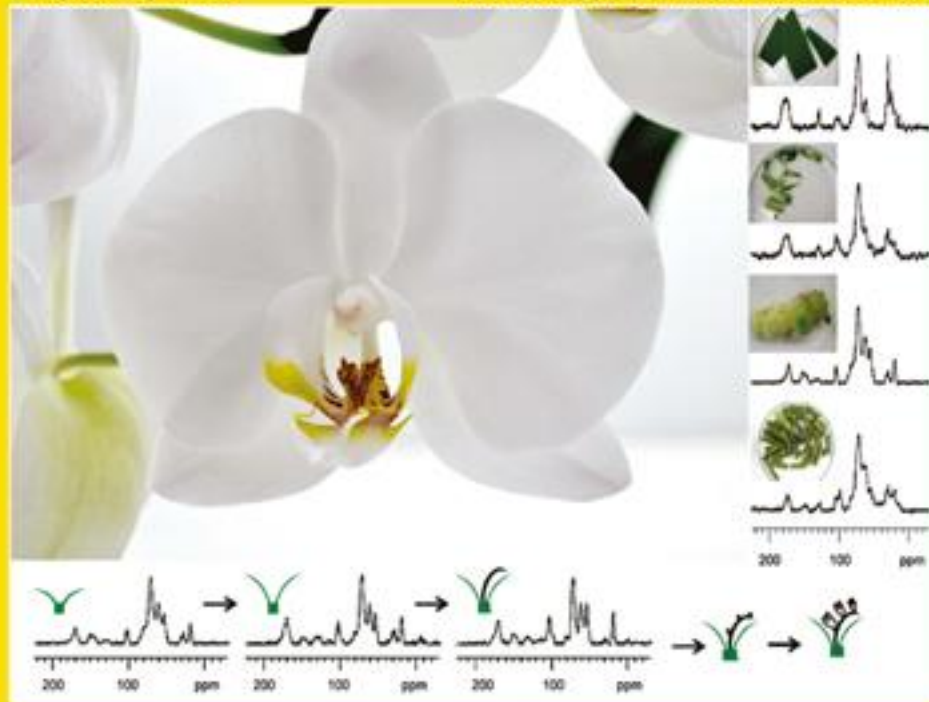
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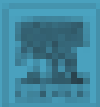
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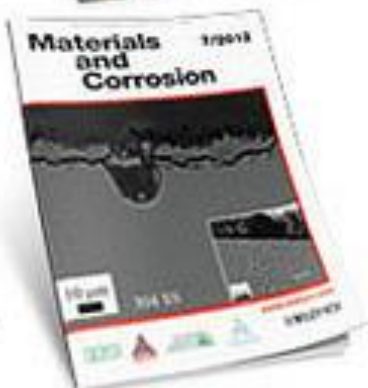
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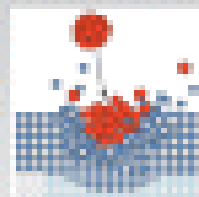
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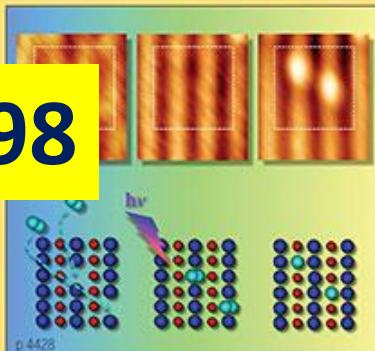
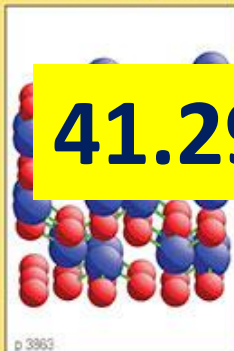
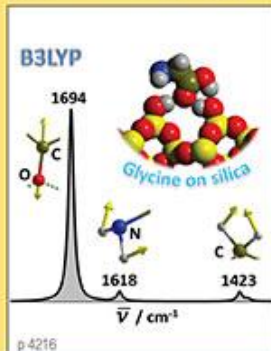
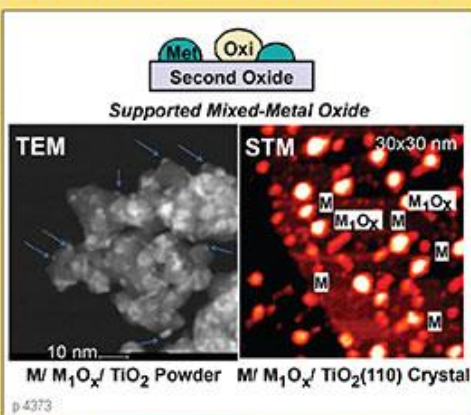
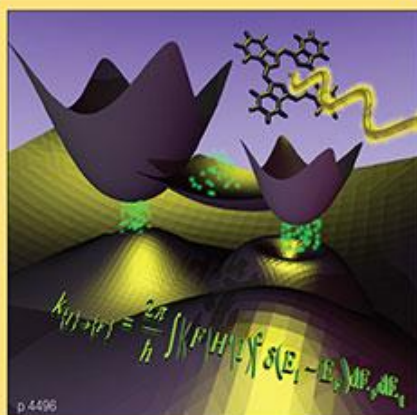
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Green Computing

Environmentally Sustainable Infrastructure Design

Green Maturity Model for Virtualization

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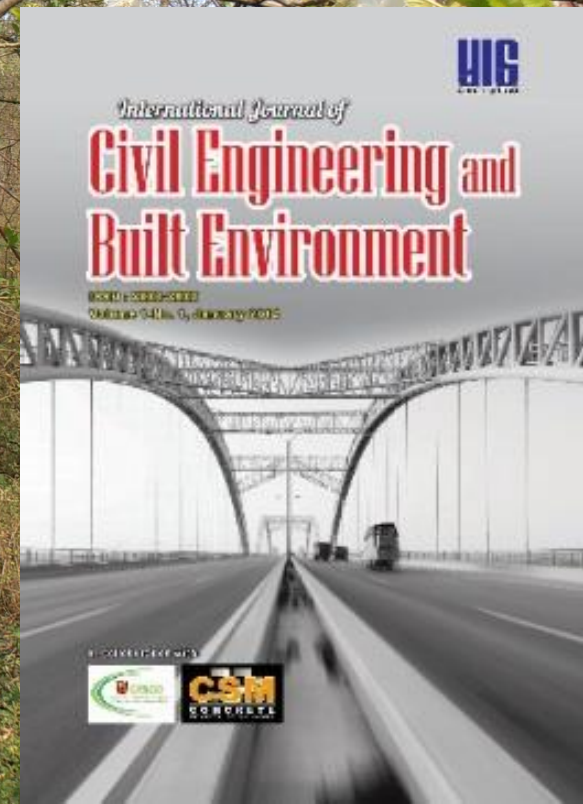
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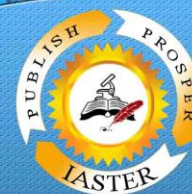
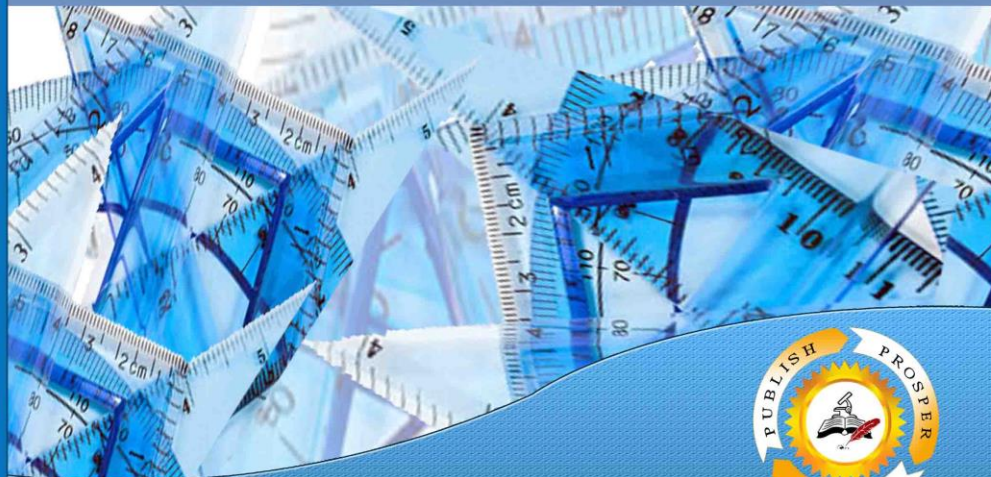
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A dense thicket of green plants with yellow and blue flowers. The plants are growing in a wooded area, with tree trunks visible in the background. The yellow flowers are small and numerous, while the blue flowers are larger and more prominent. The overall scene is a lush, green landscape with a variety of plant life.

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