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Corrosion Protection of Carbon Steel by using Simvastatin Drug in HCl Medium

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ABSTRACT

Simvastatin drug was utilized as an inhibitor for carbon steel (CS) corrosion in 1 M HCl by utilizing many techniques: weight loss (WL), hydrogen evaluation (HE), open circuit potential (E_{ocp}), electrochemical frequency modulation (EFM), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization (PP) techniques. WL is investigated at various temperatures between (25–45^{o}C) but hydrogen evaluation and all electrochemical studies at room temperature. The inhibition efficiency (% IE), increases with expanding doses of the Simvastatin drug. The activation and the variables of adsorption were investigated and calculated by the effect of temperature on the inhibition of corrosion. The adsorption of the Simvastatin on CS surface was found to obey with Langmuir adsorption model. The morphology of inhibited CS was analyzed by the energy dispersive X-ray spectroscope (EDX), atomic force microscopy (AFM) and scanning electron microscope (SEM). All techniques were utilized to examine the corrosion inhibition of the drug. Polarization data revealed that this drug affect both anodic and cathodic reactions.

Keywords: Corrosion inhibition, HCl, CS, Adsorption, SEM, EDX, AFM.

INTRODUCTION

The most methods for protection of metals from corrosion are investigated by utilization of inhibitors that especially in acid medium [1-2]. The well-known acidic inhibitors are drugs and organic compounds that contain O, S, N (N-heterocyclic), long carbon chain and aromatic compounds. The organic inhibitors have many advantages such as high %IE, cheap, friendly to the environment and easily to produce [3-5]**.** Pharmaceutical drugs like heterocyclic compounds are used for to reduced corrosion process of Fe, Cu and Al [6-16] in various aqueous medium. Adsorption of the drug facilitate the protection of the metal surface [17]. A few medications such as tetracycline, cloxcillin, azithromycin, ampiclox, ampicillin and orphenadrine were discovered to have a great inhibition for corrosion of metals and alloys. Numerous authors for the most part concur that medications are inhibitors that can compete favorably with green inhibition of corrosion and that most medications can be synthesized from natural products. Selection of some medication as corrosion inhibitors due to the followings: (1) drug molecules contain oxygen, sulphur and nitrogen as active sites, (2) it is environmentally friendly furthermore vital in organic responses and (3) drugs can be easily produced and purified [18-22]. A few medications have been discovered to be a

great corrosion inhibitors for metals such as: Biopolymer gave 86% IE for Cu in NaCl [23], pyromellitic diimide linked to oxadiazole cycle gave 84.6% IE for CS in HCl [24], 2-mercaptobenzimidazole gave 82% IE for CS in HCl [25], Antidiabetic Drug Janumet gave 88.7% IE for MS in HCl [26], Januvia gave 79.5% IE for Zn in HCl[27], Cefuroxime Axetil gave 89.9% IE for Al in HCl [28], Phenytoin sodium gave 79% for CS in HCl [29], Aspirin gave71% IE for MS in H2SO4 [30], Septazole gave 84.8% IE for Cu in HCl [31] and Chloroquine diphosphate gave 80% IE for MS in HCl [32].

The scope of this paper is to use Simvastatin drug as save corrosion inhibitor for CS in acid medium by various chemical and electrochemical methods, and to elucidate the mechanism of corrosion inhibition.

MATERIALS AND METHODS

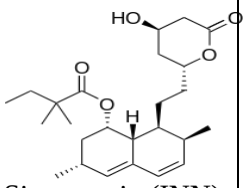
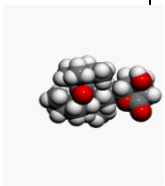
Metal sample: The composition of metal sample is listed in (Table 1).

Table 1. The component of the CS under study (wt %)

Constituent	C	Mn	P	Si	Iron
Composition %	0.2	0.6	0.04	0.003	Rest

Inhibitor: Simvastatin drug is an organic compound which describing in (Table 2). The pharmaceutical drug which was investigated is purchased from Sandozinc and Pfizer inc., companies

Table 2. The Component and molecular structure of the investigated drug

Inhibitor	**Structure**		**IUPAC Name**	**Molecular weight**	**Active center**	**Chemical formula**
Simvastatin	 Simvastatin (INN)		3*R*, 7*S*, 8*S*, 8a*R*) – 8 - {2 -[(2*R*, 4*R*) – 4 – hydroxyl -6 – oxotetrahydro - 2*H* – pyran – 2 - yl]ethyl} - 3, 7 – dimethyl - 1, 2, 3, 7, 8, 8a – hexahydronaphthalen - 1-yl 2,2-dimethylbutanoate	418.566 g/mol	**5O 2π bond**	$C_{25}H_{38}O_5$

Corrosive medium: The corrosive medium is 1M HCl, which prepared by diluted the (%37) HCl with distill water and the different concentrations of inhibitor (50, 100, 150, 200, 250 and 300 ppm) were prepared by dilution

Weight loss (WL) technique: For WL estimations, coins have the area surface (2 cm x 2 cm) x 2 which presented to the destructive solution that utilized. The coins were scraped with SiC polisher sheet coarseness sizes (400, 800 and 1200) and clean with $(CH_3)_2CO$. At that point clean a few times with bi-distilled water, lastly dried by soft tissue. The WL estimations were done in a 100 mL glass measuring beaker put in an indoor regulator thermostat or water path. The coins were then quickly dipped in the test medium in nonexistence and existence dissimilar doses of the examined compound.
All aggressive corrosive medium were opened to air. After three hour, the coins were taken out, washed, dried, and weighted correctly per thirty minutes. The average WL for seven square CS specimens will be obtained.

The % IE and surface coverage (θ) of Simvastatin for the corrosion of CS were determinate from the following equation [33]:

$$IE\% = \theta x100 = [1-(W/Wo)] X\ 100 \quad (1)$$

Where, W^o and W are the WLs in the nonexistence and existence of adding various doses of investigate drug respectively.

Hydrogen evolution (HE) technique: Measurements of HE were estimated at 25°C, and the H_2 volume developed and recorded every 15 minutes, θ and % IE were determination by (3) and (4).

$$V = K\ t \quad (2)$$

Where, V is the volume of H_2 in ml, K is rate constant and t is time in minute.

$$\Theta = 1 - K/K^o \quad (3)$$

Where, K^o and K are the rate constant of corrosion in absence and presence inhibitor, that calculated by plotting V vs. t and K value is the slope.

$$\% IE = \Theta \times 100 \quad (4)$$

PP technique: Polarization tests were done in a traditional three-anode cell with a Pt counter electrode terminal and an immersed calomel pool (SCE) as the reference pool. The working electrode which consists of a square sheet from CS settled in epoxy resin like polytetrafluoroethylene which don't affect by acid and covered the coin sample until the level surface that have 1.0 cm^2 area. The working terminal was polished with SiC polisher papers. Before estimation, the electrode was submerged in corrosive medium at normal potential for 30 min. until the point when an enduring or steady state was come to. The potential of open circuit (E_{ocp}) started in the blank -533 mV and the presence different doses of simvastatin drug started from -497 to 470.2 mV. All tests were done in newly arranged or preparing corrosive medium at room temperature and the data were constantly rehashed no less than three times to check the accuracy or valid results. Determination of % IE and the θ as below [34]:

$$\% \boldsymbol{IE} = \boldsymbol{\theta} \times \mathbf{100} = \left[\mathbf{1} - \frac{\boldsymbol{i_{corr(inh)}}}{\boldsymbol{i_{corr(free)}}} \right] \times \mathbf{100} \quad (\mathbf{5})$$

Where, $i_{corr(free)}$ and $i_{corr(inh)}$ are the densities of oxidation current in the nonexistence and existence of Simvastatin drug as an inhibitor, in that order.

EIS technique: All EIS measuring data were performing at open circuit potential E_{ocp} at 25±1°C more than a broad frequency range of ($1x10^5$ Hz to x 0.1 Hz). The perturbation potential was 10 mV in abundance peak to peak. The obtain diameters of the capacitive loops raise in occurrence of Simvastatin drug and indicated of the capacity of the extent of inhibition of oxidation progression, contrary to the diminished of the capacitance of double layers (C_{dl}) which is determination by:

$$\boldsymbol{C_{dl}} = \frac{\mathbf{1}}{(\mathbf{2\pi} \boldsymbol{f_{max}} \boldsymbol{R_p})} \quad (\mathbf{6})$$

Where, f_{max} is the highest frequency.

The % IE and the (θ) acquired from the impedance estimations were characterized by the accompanying connection:

$$\% \boldsymbol{IE} = \boldsymbol{\theta} \times \mathbf{100} = \left[\mathbf{1} - \frac{\boldsymbol{R_p^o}}{\boldsymbol{R_p}} \right] \times \mathbf{100} \quad (\mathbf{7})$$

Where, $R°_p$ and R_p are resistance of the charge move in the nonattendance and nearness of Simvastatin, separately.

EFM technique: The large peaks were utilized for the determination of the corrosion current density (i_{corr}), the Tafel inclines (β_c and β_a) and the causality factors CF_2 and CF_3 [35-36]. The $\% IE_{EFM}$ was calculated as follows:

$$\% \boldsymbol{IE_{EFM}} = \left[\mathbf{1} - \frac{\boldsymbol{i_{corr}}}{\boldsymbol{i_{corr}^o}} \right] \times \mathbf{100} \quad (\mathbf{8})$$

Where, i^{o}_{corr} and i_{corr} are densities of the corrosion current in the nonexistence and existence of Simvastatin drug. All potentiodynamic, open circuit potential, EIS and EFM as electrochemical analysis were investigated by utilizing Gamry tool PCI300/4.

Surface Examinations: The CS specimens utilized for analysis of surface morphology were prepared in 1M HCl acid (blank) and with 300 ppm of Simvastatin at room temperature for one day after abraded automatically utilizing various emery sheets up to 1200 gravel size. Then, after this the coins were dipped in corrosive medium at even time, the coins were cleaned quietly with distill water, charily dried and mount into the performed specimens examined by using SEM, EDX and AFM.

RESULTS AND DISCUSSION

WL measurement: The WL of CS relative to the surface area at different time periods in the nonexistence and existence of various doses (50, 100, 150, 200, 250 and 300 ppm) of the Simvastatin. The bends lines or curves acquired within the sight of various doses of drug fall essentially underneath that of free corrosive medium as appeared in (Figure-1).

The % IE is recorded in (Table 3). In all cases, the IE of the drug increment with expanding doses of drug but the rate of corrosion was decreased. These results indicated that, the Simvastatin under study is good substance that prevent CS oxidation in corrosive medium.

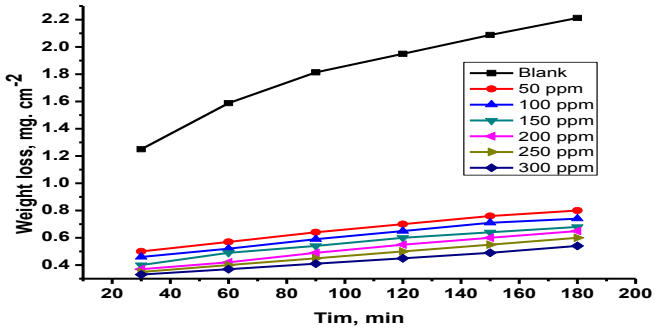


Figure 1: W L-time bending curves for the oxidation of CS in the nonexistence and existence of various doses of Simvastatin at 25°C

Table 3. Variation of % IE of Simvastatin with various doses at 25°C from WL testing at 120 min dipping in 1 M hydrochloric acid

Compound	Conc. ppm	$k_{corr.}x10^{-3}$ mg cm^{-2} min^{-1}	% IE
Blank	---	16.25	----
Simvastatin	50	5.42	66.7
	100	5.00	69.2
	150	4.58	71.8
	200	4.25	73.9
	250	4.00	75.4
	300	3.83	76.4

Temperature effect: Study the effect of temperature by applied Arrhenius equation and the rate of corrosion ($k_{corr.}$) can be determined:

$$\log k_{corr} = A - \left[\frac{E_a}{2.303\,RT}\right] \qquad (9)$$

Where, E_a is the activation of inhibition for the oxidation of CS in corrosive medium in nonexistence and existence of Simvastatin inhibitor, R is universal gases constant, T is absolute temperature and A is Arrhenius pre-exponential consistent relies upon the metal sort and electrolyte. Arrhenius plots of log k_{corr}. vs (1/T) for CS in 1 M hydrochloric acid in the nonexistence and existence of various doses of Simvastatin drug is shown graphically in (Figure 2). The variety of log k_{corr} vs (1/T) is straight lines and the estimation of E_a got is recorded in (Table 4). These outcomes propose that the drug is comparative in the system of activity. The expansion in E^*_a with the expansion of various doses of inhibitor, demonstrating that, the energy limit for the oxidation reduction expanded. After additionally shown that the entire procedure is controlled by the relative of surface corroded occurs, since the actuation energy of the consumption oxidation process is > 20 kJ mol^{-1} [37].

The (ΔS^*, ΔH^*) of activation are determinate from the theory of transition state by applied the following relation [38].

$$k_{corr} = \left[\frac{RT}{Nh}\right] \exp\left(\frac{\Delta S^*}{R}\right) \exp\left(\frac{\Delta H^*}{RT}\right) \qquad (10)$$

Where, N is Avogadro's number, h is Planck's constant. A plot of log (k_{corr}/T) versus (1/T) likewise gave straight lines as appeared in (Figure-3), for CS dissolution in one molar hydrochloric acid in the absence and presence of changed doses of Simvastatin. The slopes of these lines equal $-\Delta H^*/2.303R$ and the intercept rise to log [RT/Nh] + ($\Delta S^*/2.303R$), that the estimation of ΔH^* and ΔS^* were determination and recorded in (Table 4). These outcomes demonstrate that they the used compound acts as inhibitor. The estimations of ΔH^* are reflected the strength of the adsorption of this drug on CS surface. The estimations of ΔS^* without and with the used compound is large and negative; this demonstrates that the rate-deciding step is association rather than dissolution [39].

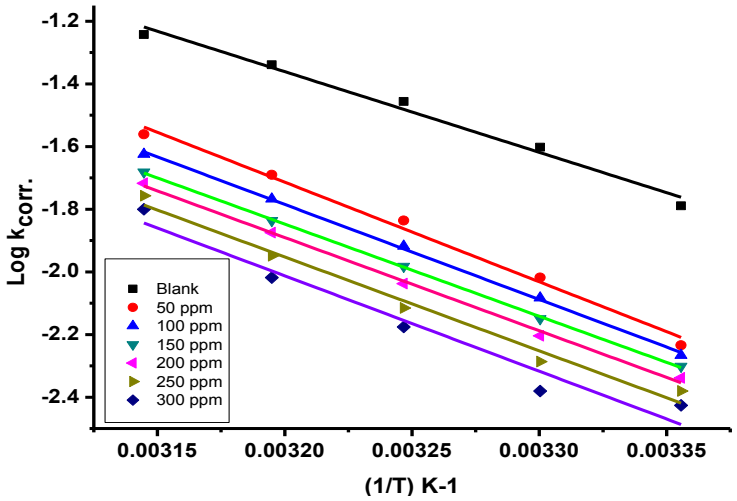


Figure 2: Diagram (log k_{corr} vs 1/ T) for oxidation of CS in HCl acid in the nonexistence and existence of various doses of Simvastatin

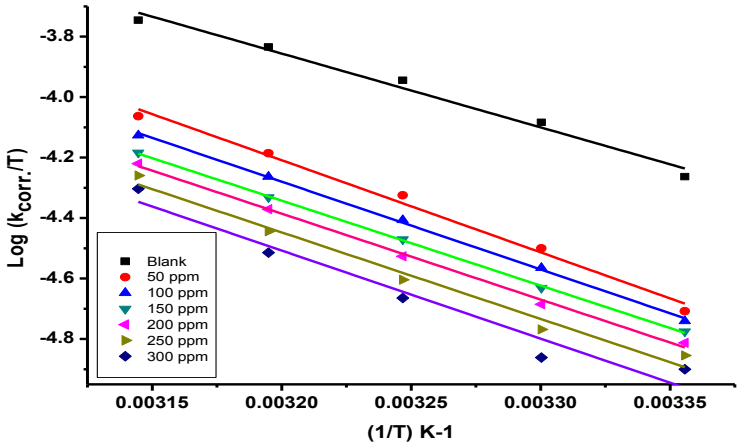


Figure 3: Diagram (log k_{corr} / T) vs (1/ T) for oxidation of CS in 1 M HCl in the nonexistence and existence of variant doses of Simvastatin at 25°C.

Table 4. E^*_a , ΔH^* and ΔS^*variables for the oxidation of CS in 1 M hydrochloric acid in the nonexistence and existence of variant doses of tested drug

Conc. Ppm	Activation parameters		
	E^*_a kJ mol^{-1}	ΔH^* kJ mol^{-1}	$-\Delta S^*$ J mol^{-1} K^{-1}
Blank	42.3	40.4	142.2
50	53.8	52.1	111.5
100	54.1	52.5	111.4
150	54.9	53.4	109.9
200	57.5	55.9	102.5
250	62.1	60.9	87.9
300	67.0	65.9	72.8

Adsorption isotherms: Simvastatin adsorbed on the metal and the values of (θ) for various doses of drug in one molar hydrochloric acid was determinate from WL data utilizing the follows relation:

$$\boldsymbol{\theta} = \left[\frac{\boldsymbol{weight\ loss_{(pure)} - weight\ loss_{(inh)}}}{\boldsymbol{weight\ loss_{(pure)}}}\right] \qquad (\mathbf{11})$$

From the Θ values, it is obvious that increment with raising the doses of Simvastatin. By utilizing these values and for applying various adsorption isotherms Langmuir adsorption was found the best one and to follow the next relation [40].

$$\mathbf{C/\theta = 1/K_{ads} + C} \qquad \mathbf{(12)}$$

Where, $K_{ads.}$ is the equilibrium constant of adsorption. Plotting (C/Θ) against (C) of Simvastatin at various temperatures is shown in (Figure-4). The linear relationship is given with intercept equal to ($1/K_{asd.}$) and slope similar the unity, the adsorption constant being result to the standard free energy of ΔG^o_{ads} by follows:

$$\boldsymbol{\Delta G^o_{ads} = -RTln\ (55.5\ K_{ads})} \qquad (\mathbf{13})$$

Where, R is the gerenral gas constant, T is the absolute temperature and 55.5 is the doses of water in the solution in M/L. The $\Delta G^o_{ads.}$ values at all studied at different temperatures which determined by above equation (13) and recorded in (Table 5). The ($\Delta H^o_{ads.}$) was determined according to the Van't Hoff equation [41].

$$\log k_{ads} = \left(\frac{-\Delta H^{\circ}_{ads}}{2.303RT}\right) + constant \qquad (14)$$

Plotting (log $K_{ads.}$) against (1/T) give straight lines as shown in (Figure-5), the straight lines give slope equal ($\Delta H^{o}_{ads.}$/2.303R), from this slope; the ΔH^{o}_{ads} values were calculated and are listed in (Table 5). Then by applying the following equation:

$$\Delta G^{o}_{ads} = \Delta H^{o}_{ads.} - T\Delta S^{o}_{ads.} \qquad (15)$$

From introducing the values of ΔG^{o}_{ads} and $\Delta H^{o}_{ads.}$, the ΔS^{o}_{ads} was calculated at all studied temperatures from the above eq. (15). All thermodynamic adsorption parameters for Simvastatin inhibitor on CS from 1M HCl medium can be concluded that:

1- The correlation coefficients between (0.99 - 0.98) reflected that the experimental data give good curves fitting for the adsorption isotherm, and K_{ads} values increase with increasing temperatures from 25 to 45°C
2- The negative values of ΔG^{o}_{ads} reflect that the adsorption of Simvastatin on CS surface in 1 M hydrochloric acid solution is spontaneous process.
3- The ΔG^{o}_{ads} values are around -20 kJ mol^{-1} or less lead to the Van Der Waal's forces or electro-static attraction between positive charged of metal surface or vacant space in valance orbital's of the metal surface accepted electrons to form semi coordination bond and the negative charge of Simvastatin molecules in the bulk of the medium i.e. physical adsorption.
4- The negative sign of ΔH^{o}_{ads} refer to the adsorption of inhibitor molecules is an exothermic process, indicating that the adsorption is physical adsorption. The unshared pairs electron from investigate molecule may attractive with positive center on the surface of CS by electrostatic attraction to provide a protective film prevent corrosion process [42].
5- The ΔS^{o}_{ads} values, in the existence of the investigate drug are negative and large that is accompanied with exothermic adsorption process [43].

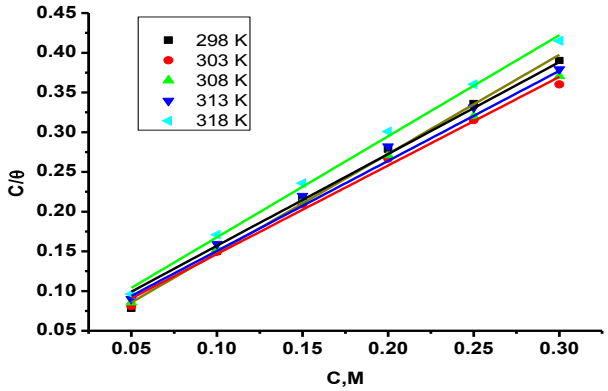


Figure 4: Diagram illustrate the Langmuir adsorption that plotted (log C) against (C/θ) of the simvastatin drug for corrosion of CS in 1 M HCl from WL technique at 25°C

Table 5. K_{ads} and adsorption free energy (ΔG°_{ads}) for the adsorption of Simvastatin on CS in 1 M hydrochloric acid from WL method at 25°C

Temp. °C c	K_{ads} M^{-1}	$-\Delta G^{o}_{ads}$ kJ mol^{-1}	$-\Delta H^{o}_{ads}$ kJ mol^{-1}	$-\Delta S^{o}_{ads}$ J $mol^{-1}K^{-1}$
25	42.55	19.25	20.16	3.06
30	28.44	18.55		5.30
35	26.79	18.71		4.72
40	24.17	18.74		4.52
45	24.63	19.09		3.36

HE tests: All information drowns from the volume of hydrogen which produces versus time, from the different doses (50 – 300 ppm) of Simvastatin that shown in (Figure-6). The slope of lines evaluated of the rate of corrosion. The great straight lines are shown that the insoluble film on the metal surface. The certain of the rate of corrosion acquired from hydrogen evaluation individually at various doses are recorded in (Table 6). The rate of corrosion reduced with increasing of Simvastatin doses.

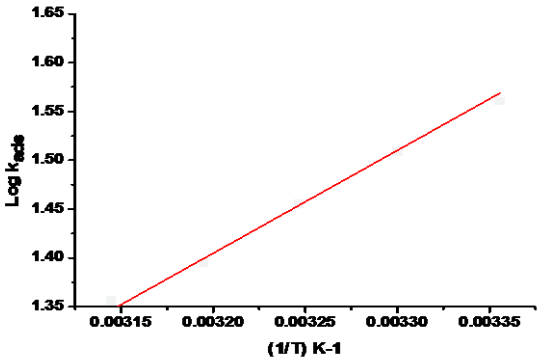


Figure 5: (log K_{ads}) vs (1/T) for the corrosion of CS in 1M HCl in the existence of Simvastatin at various temperatures

Table 6. The rate of corrosion for metal at presence different doses of Simvastatin inhibitor

Conc. ppm	k_{corr} ml cm^{-2} min^{-1}	Θ	% IE
Blank	0.158	------	------
50	0.062	0.608	60.8
100	0.059	0.627	62.7
150	0.056	0.646	64.6
200	0.053	0.665	66.5
250	0.050	0.684	68.4
300	0.046	0.709	70.9

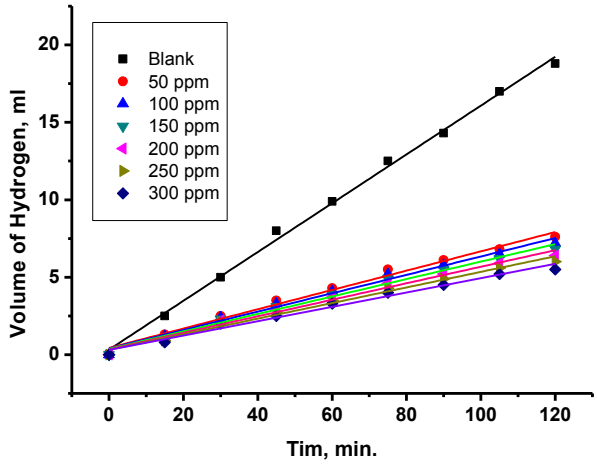


Figure 6: HE produced versus time with and without various doses of drug at 25°C

Open circuit potential (E_{ocp}): From the (Figure-7) is shown several interesting points:

1. The E_{OPC} in the blank solution is beginning from -533 mV then shifted anodically and reached the steady state after 300 second indicating that the initial dissolution process and formation oxide film on the metal surface.

2. The E_{OCP} is started in the existence of Simvastatin, at less negatively potential compared with that in the nonexistence of the drug and then shifted anodically, according to the increasing the doses 50, 100, 150, 200, 250 and 300 respectively, that shown in (Table 7). The steady state is attained rapidly, with increasing the doses of the drug comparing with the blank, and then the shift in the potential of E_{OCP} increment in the positive direction position and the drug might certain act as an anodic inhibitor [44]. However, from (Figure-7), the shift in E_{OCP} on addition Simvastatin is about 57.5 mV revealing that the present drug acts as anodically drug.

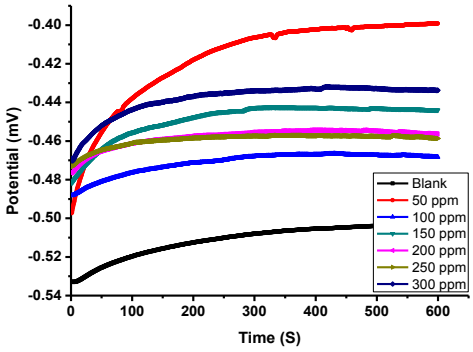


Figure 7: Open circuit potential, E_{ocp} vs. time relations for CS submersion in 1M hydrochloric acid in the nonexistence and existence of Simvastatin drug at 25°C

Table 7. E_{ocp} of the CS in the nonexistence and in existence of Simvastatin drug at 25°C

Conc. Ppm Simvastatin	$-E_{Min}$ (mV)	$-E_{Max}$ (mV)
Blank	533.0	502.0
50	497.5	399.2
100	488.2	466.5
150	481.6	442.5
200	476.6	454.4
250	473.3	457.1
300	470.2	432.6

PP tests: PP is carrying out in 1 M HCl acid medium in the nonexistence and existence of different doses of Simvastatin at 25°C. The results are drowning in (Figure-8). The PP variables are recorded in (Table 8). These outcomes information showing that the cathodic and anodic bends lines gotten by Tafel-type behavior. The type of the bends lines is fundamentally the same which shows the dissolution of the mechanism of CS and hydrogen evolution obviously stay without changing. Expansion of Simvastatin reduces the corrosion current. The small change of the E_{corr} revealed that the drug acts as mixed one [45].

The information data additionally demonstrate that the inclines of the anodic and the cathodic Tafel slants (β_a & β_c) were slightly changed on expanding the doses of the used compound. This demonstrates that there is no change of mechanism but % IE increment with expanding doses of simvastatin.

The way of the approximations of β_c are somewhat higher than the approximations of β_a this is attributed to the cathodic activity of the drug. The steadiness and the cathodic incline gotten from the electrochemical estimations demonstrate that the hydrogen evolution reaction was activation controlled [46] when the adding of the Simvastatin did not alter the mechanism of this process.

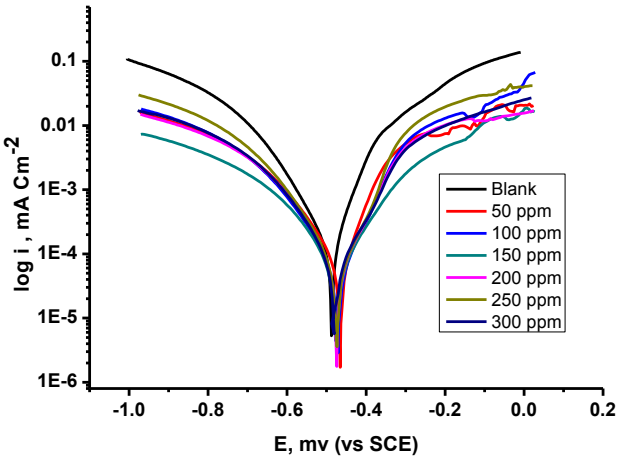


Figure 8: The PP curves for the oxidation of CS in 1M HCl in the nonexistence and existence of varied doses of Simvastatin at 25°C

Table 8. The effect of doses of Simvastatin on the E_{corr}, i_{corr}, Tafel slopes (β_a& β_c), % IE , and Θ for the oxidation of CS in 1M HCl at 25 °C

Conc. ppm	$I_{corr.}$ mA/cm^{-2}	$-E_{corr.}$ mV(SCE)	β_a mV dec^{-1}	β_c mV dec^{-1}	C. R. Mpy	Θ	% IE
0.0	147	480	166	208	67.3	----	----
50	63.8	476	118	118	29.14	0.578	57.8
100	63.4	468	79.9	129	28.97	0.580	58.0
150	59.4	476	112	109	27.14	0.607	60.7
200	58.2	462	63.3	114	26.58	0.615	61.5
250	42.6	482	88.5	94.9	19.45	0.718	71.8
300	30.5	464	40.1	70.9	13.96	0.798	79.8

EIS tests: The (EIS) charts (Nyquist and bode) at frequencies extending range between 0.1 Hz to 10^5 Hz with 10 mV plenitude position at OCP for CS in one molar hydrochloric acid in the nonexistence and existence of varied measurements of Simvastatin doses are acquired. The identical circuit that describe for (CS) and electrolyte are found in (Figure-9), EIS variables and % IE were determined and recorded in (Table 9). The obtained Nyquist and Bode that are plotting in curves for Simvastatin are shown in (Figure-10). Nyquist spectra are described by a semicircle. These demonstrate that the oxidation of CS is restricted by a charge transfer process [47]. The diameter of the capacitive circle acquired increments within the sight of Simvastatin were demonstrated that the expanding the level of inhibition of the consumption oxidation process [48].

From the results of (EIS) that obtained R_p rises and C_{dl} reducing with increasing of Simvastatin drug doses. The increase in R_p values improve the increase of the % IE because of the progressive substituent of water particles by the adsorption of the medication particles on the metal surface by an adherence film form on

the metal surface. The formation film on the metal surface reduced the double layer thickness. Also, the decreasing of C_{dl} with rises the drug doses as result from reduce in local dielectric constant which indicating that, the drug was adsorbed on anodic sites and covered the cathodic sites on the surface of the metal [49].

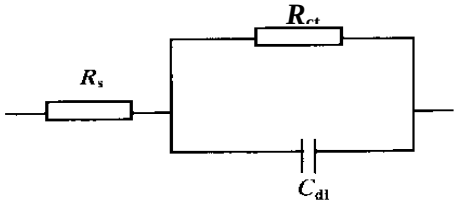
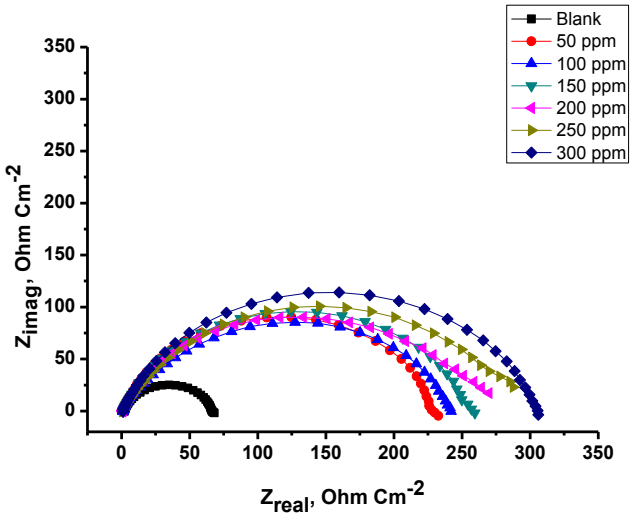
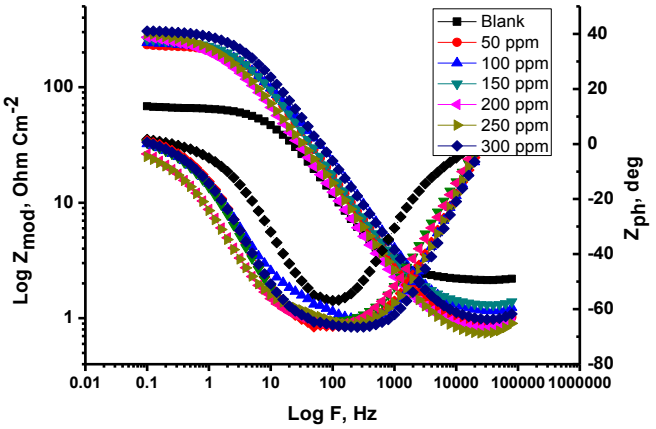


Figure 9: Circuit model used to fit the experimental data, R_s refer to solution resistance and R_p or R_{ct} charge transfer resistance, respectively



(a)



(b)

Figure 10: The Nyquist (a) and Bode (b) plots for oxidation of CS in one 1M HCl in the nonexistence and existence of various doses of Simvastatin at 25 °C

Table 9. Electrochemical kinetic variables occur by EIS technique for oxidation of CS in 1M HCl nonexistence and existence various doses of Simvastatin at 25 ^{o}C

Conc. ppm	R_p Ω cm^2	C_{dl} µF cm^2	Θ	% IE
0.0	64.7	594	-----	-----
50	170.6	69	0.621	62.1
100	205.5	55.9	0.685	68.5
150	225.5	49.3	0.713	71.3
200	258.1	36.9	0.749	74.9
250	278.7	29.9	0.768	76.8
300	280.9	27.4	0.769	76.9

EFM tests: EFM is regarded a very good technique to determination corrosion information directly and quickly because EFM is nondestructive technique to determination corrosion [50]. The measurements data of EFM are become a valid data when the practical causality factors (CF2 and CF3) are equals or near the hypothetical values (2 and 3) which determination from the frequency spectrum of the current reaction. (Figure-11), illustrated the EFM inter-modulation spectrum of CS in 1 M hydrochloric acid in nonexistence and existence deferent doses of Simvastatin drug. It clearly that the treatment EFM data utilizing two various models: (1) the activation model by solved three nonlinear equation and assuming no change of the corrosion potential due to the polarization of the working electrode (2) cathodic reaction controlled by complete diffusion [51].

The density of corrosion current (i_{corr}), the (β_a and β_c) and (CF2 and CF3) are calculated from the two large peaks of inter-modulation spectrum, and then recorded in (Table 10). It is obviously, that the addition of tested Simvastatin at given doses to the corrosive medium reducing the (i_{corr}), indicating that the Simvastatin inhibits the corrosion of CS by the adsorption process. The (CF2 and CF3) are equal to the hypothetical values (2 and 3) indicative of that the estimation information are valid and good value [52]. The % IE $_{EFM}$ values are increments by expanding the doses of Simvastatin which determination and recorded in (Table 10).

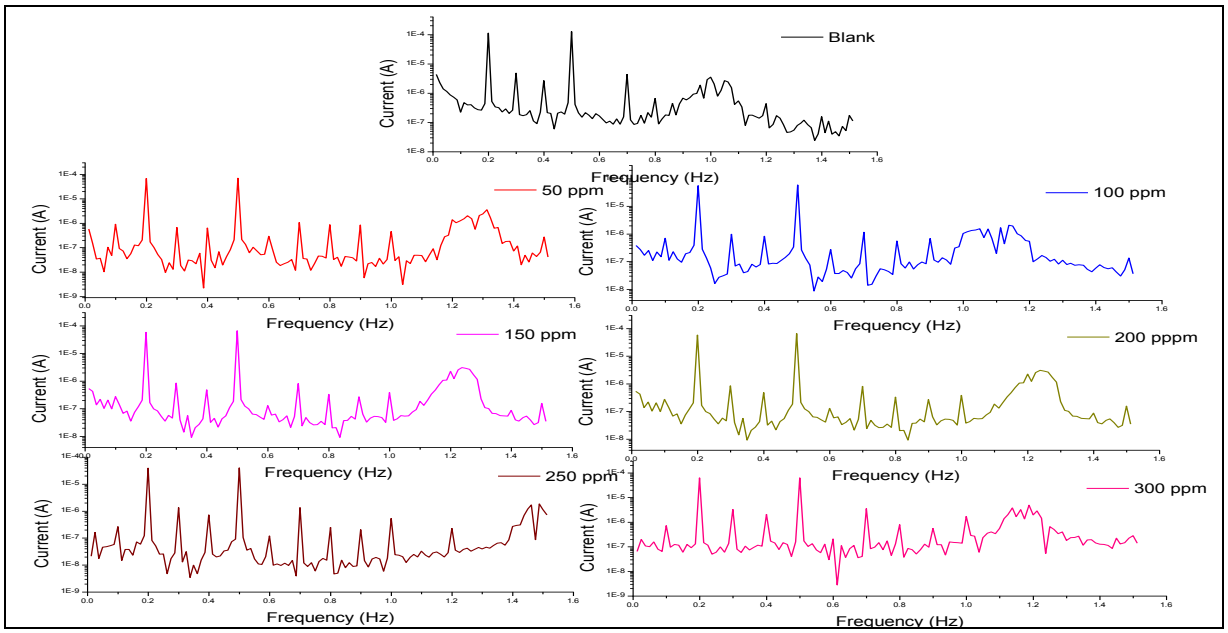
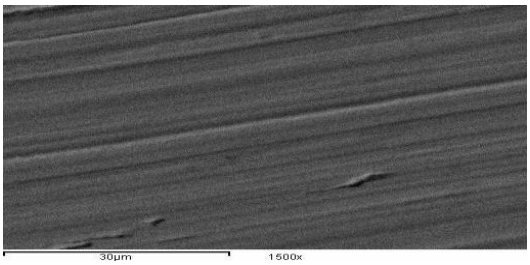


Figure 11: EFM for CS in 1M HCl with and without various doses of the used Simvastatin

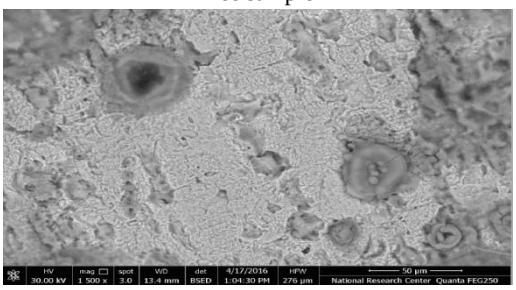
Table 10. Electrochemical kinetic variables occur by EFM method for CS in 1 M HCl nonexistence and existence different doses of Simvastatin at 25 ^{o}C

Comp.	Conc. M	$i_{corr.}$ μAcm^{-2}	β_a x 10^{-3} $mVdec^{-1}$	β_c x 10^{-3} $mVdec^{-1}$	CF (2)	CF (3)	CR Mpy	Θ	%IE
Blank	0.0	350.3	156.4	247.9	1.5	2.9	160.1	----	----
Simvastatin	50	100.9	92.3	99.4	1.6	3.5	46.1	0.712	71.2
	100	98.3	104.7	119.0	1.2	3	44.9	0.719	71.9
	150	96.5	98.3	107.1	1.9	5.4	44.1	0.724	72.4
	200	94.2	104.6	115.8	2	3.3	43.0	0.731	73.1
	250	92.7	132.7	183.3	2	5	42.4	0.735	73.5
	300	89.2	81.0	111.3	1.8	4	40.8	0.745	74.5

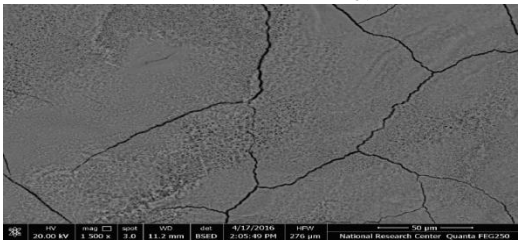
SEM analysis: (Figure-12), refer the micro-graph obtain for CS coins in existence and in nonexistence of 300 ppm of Simvastatin after contact for 1 day submersion. It is obvious that CS surfaces help and enhance corrosion aggression in corrosive medium by inter-granule corrosion. The coin morphology of CS surface is smooth before immersion in the corrosive medium with 300 ppm of Simvastatin drug which adsorbed on surface of metal and formation thin film. We are clear that the development of a film which is dispersed in a request route in general or in the whole surface of the CS. This might be because of the adsorption of the Simvastatin on the CS surface and make the passive film keeping in mind the end goal to obstruct the dynamic site introduce on the CS surface. The inhibitor particle association with dynamic locales of CS surface, resulting in a reduction in the contact between CS and the destructive medium and consecutively displayed superb restraint impact [53-54]



Free sample



Blank (in 1M HCl only)



In 1M HCl with existence 300 ppm of Simvastatin

Figure 12: SEM micrographs for CS in the nonexistence and existence of 300 ppm of Simvastatin after immersion for 1 day

EDX analysis: To determination of existence elements which adsorbed on CS surface by EDX spectrum after I day immersion in one molar hydrochloric acid with optimum doses of Simvastatin drug. (Figure-13), gives the EDX examination of CS in one molar hydrochloric acid with within the sight of 300ppm of Simvastatin. The spectrum demonstrates extra lines, showing the presence of C (inferable from the carbon atoms of some Simvastatin). This information demonstrates that the C and O atoms secured the coins surface. The elements carbon and oxygen was determination by EDX analysis and shown that passivation film contained the chemical formula of Simvastatin drug adsorbed on the surface of CS. It is seen that, the percent weight of adsorb elements C and O were present in the spectra and recorded in (Table 11).

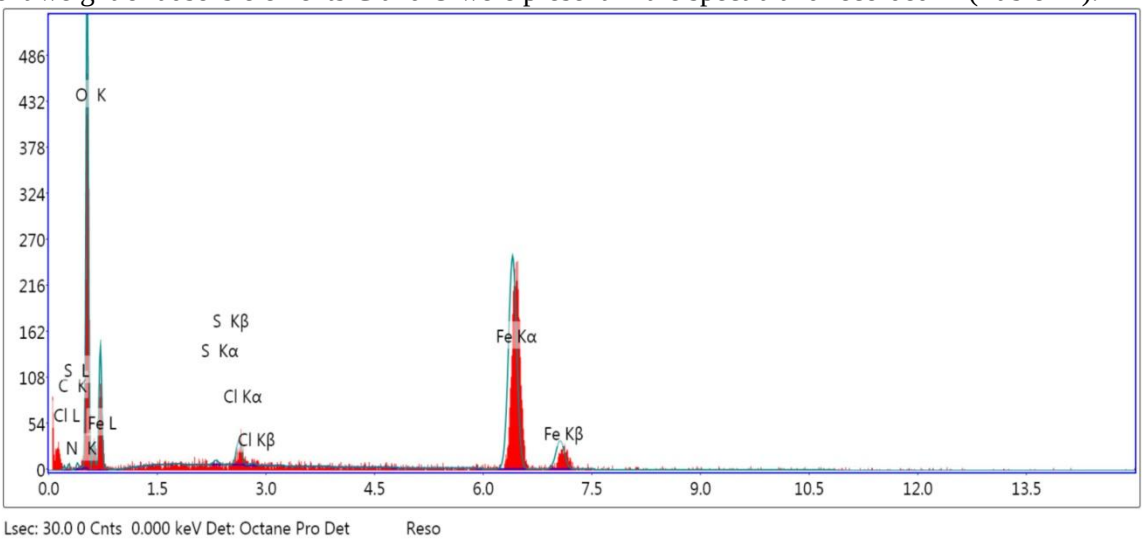
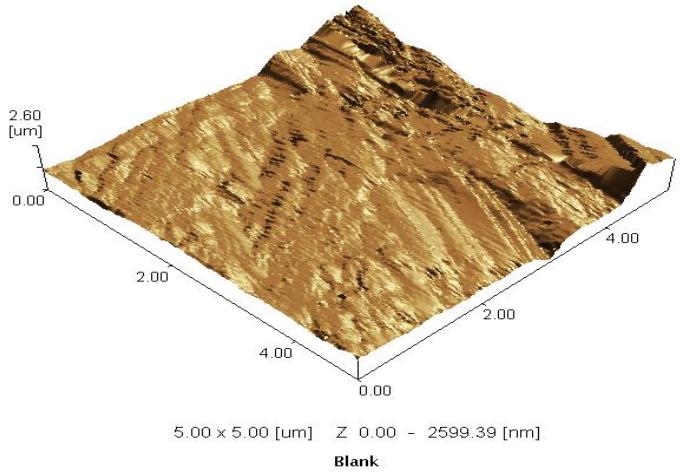


Figure 13: EDX examination on CS in the existence and nonexistence of Simvastatin for 1 day submersion.

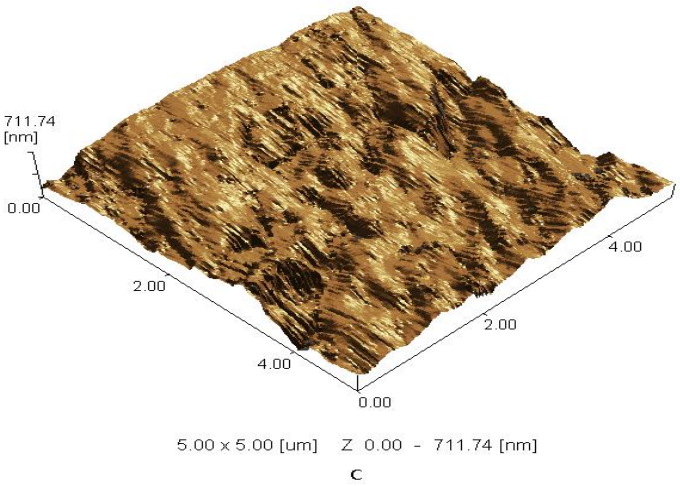
Table 11. Surface composition (% wt) of CS after one day of submersion in 1M HCl nonexistence and existence the 300 ppm of Simvastatin

(Mass %)	Fe	C	O	N	S	Cl
Pure metal	98.28	0.78	--	--	--	--
Blank	72.1	9.23	17	--	--	0.35
Simvastatin	62.16	1.32	33.54	1.14	--	1.63

AFM analysis: From the analysis, it can be gained regarding the roughness on the surface. The roughness profile values play an important role in identifying and report the efficiency of the inhibitor under study. Among the roughness take a role in explanation about the nature of the adsorbed film on the surface [55-56]. (Figure-14), shows the 3D images as well as elevation profiles of polished of CS in absence and existence Simvastatin as an inhibitor. It observed in (Figure-14), the surface of CS specimen (a) exposed to corroded solution affected vales structure with large and deep crack but the surface (b) reveal that is covering film adsorbed on the metal surface. The conclusion, that the adsorption film can protect the surface of the metal from corrosion process. Analysis of the values indicated higher the values of roughness parameter reached. The mean roughness is found to be (2.60 µm) for the blank in acid solution which placed in 1M HCl one day and analyzed. The observation of the metal surface which submersion in 1M HCl in existence of 300 ppm of Simvastatin inhibitor possesses roughness (711.74 nm) compared to the blank solution. It can be noted that the value is less than that of the blank value. The diminishing in the roughness value reflected the adsorption of Simvastatin drug molecule on metal surface thereby reducing the rate of oxidation.



(a)



(b)

Figure 14: The 3D of optical images of AFM in nonexistence (a) and existence (b) of Simvastatin drug

CONCLUSIONS

The inhibition of the consumption oxidation of CS in 1M HCl as a corrosive medium by Simvastatin is dictated by WL, hydrogen evaluation, potentiodynamic estimations, EIS, EFM, SEM, EDX and AFM examination.

1) The tried Simvastatin inhibitor set up a decent restraint for CS corrosion in HCl as the corrosive medium
2) Simvastatin inhibit the CS by adsorption on its surface and make thin film layer adsorbed on the surface of metal.
3) The %IE of the inhibitor increments with expanding of their doses.
4) Capacitances of double layer are diminishing with respect the blank corrosive medium when the Simvastatin included. This reality may clarified by adsorption of the Simvastatin particle on the CS surface.

5) Adsorption of Simvastatin compound on CS surface in HCl solution applicable by Langmuir adsorption model.
6) The estimations of % IE acquired from the diverse free procedures utilized demonstrated the valid of the occur results.

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