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Corrosion Inhibition of Copper Metal by Ethanolic Extract of *Tinospora Cordifolia* Plant in Sulfuric and Hydrochloric Acids of varying Strength (0.5 N to 3N) using Additives

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***Abstract:** Using typical weight loss and thermometric techniques, the inhibitory impact of Tinospora cordifolia stem and leaf extract on copper corrosion in H_2SO_4 and HCl solutions of varying strength(0.5N,1N,2N,3N) was investigated. The outcomes demonstrated that extracts worked as outstanding and effective inhibitors in acidic conditions, both in the absence and addition of additives. In an acidic environment, Tinospora cordifolia stem extract outperformed leaves extract in terms of inhibitory efficiency.The maximal inhibitory efficiency for stem extract at maximum inhibitor concentrations of 0.8% was 96.54% and 99.19% in 0.5 N H_2SO_4 and 95.26% & 97.78% in 0.5 N HCl, respectively, in the absence and presence of additives (KI & K_2SO_4). Similar to this, the effectiveness of the leaf extract's inhibition was 95.37% and 97.84% in 0.5 N H_2SO_4 and 94.15% and 96.92% in 0.5 N HCl, at a maximum inhibitor concentration of 0.8% in the absence and addition, respectively, of additives (KI & K_2SO_4). Based on the findings, stem extract suppresses H_2SO_4 and HCl more potently than leaf extract.Surface coverage (θ) grows as inhibitor concentration rises (from 0.2% to 0.8%).The values of log(θ/(1-θ) increase linearly as inhibitor concentration rises,it has been demonstrated that ,the inhibitor's adsorption on the copper surface in the acid solutions followed Langmuir's adsorption isotherm. The current investigation discovered that the inhibitors (stem and leaf) were more effective at inhibiting the metal copper in H_2SO_4 and HCl acid solutions when an additive (KI and K_2SO_4) was present than when the inhibitors (stem and leaf) were present alone. Synergistic effects are to blame for this. The combined action of the two chemicals is more potent on a metal surface than the combined actions of the two chemicals acting separately or concurrently.*
***Keywords:** Weight Loss, Inhibition Efficiency, Surface Coverage , Thermometric Method, Inhibitor , Tinospora Cordifolia, Corrosion Rate.*

I. INTRODUCTION

Corrosion is the deterioration of materials carried on by an environmental chemical or electrochemical assault. An environmental component is either consumed by or dissolved into a substance as a result of an inevitable interfacial contact between the substance and its surroundings. Copper is widely employed in huge equipment or machinery and many different sorts of industries because it has excellent scalability, thermal conductivity, noble metal characteristics, and electrical conductivity [1-3]. Manufacturing of wire, electrical, and electronic componentry is one instance [4]. Nevertheless, copper is often corroded during industrial production and rapidly combines with airborne oxygen to produce a variety of corrosion products, including some complex oxides. Pickling with sulphuric acid is a highly popular and successful procedure in industry to get rid of these corrosion by-products [5]. Inevitably, when cleaning, the acid solution will unavoidably harm the copper substrate in addition to eliminating all corrosion products. This will raise the likelihood of security events and result in significant financial losses [6, 7]. Including a proper corrosion inhibitor in the pickling solution is one of the most practical and efficient ways to stop copper substrate deterioration. As a result, numerous organic substances with heteroatoms (oxygen, sulfur, nitrogen, and phosphorus), conjugated double bonds, and polar functional groups have been considered corrosion inhibitors in recent years to prevent metal corrosion [8, 9]. The use of inhibitors is one of the most practical and economical options available for reducing corrosion of copper and its alloys. Organic substances with lone pair-donating heteroatoms (N, O, or S) or π-bonds typically have strong inhibitory effects [10-12]. Unfortunately, a lot of regularly used corrosion inhibitors are toxic for human beings and other creatures, hard to break down, and harmful to the environment. Current research efforts have been focused on finding new green corrosion inhibitors to replace the conventional ones in order to address these issues [13-16]. Therefore Tinospora Cordifolia plant has been selected for the study.

II. PLANT DESCRIPTION

A. Classification

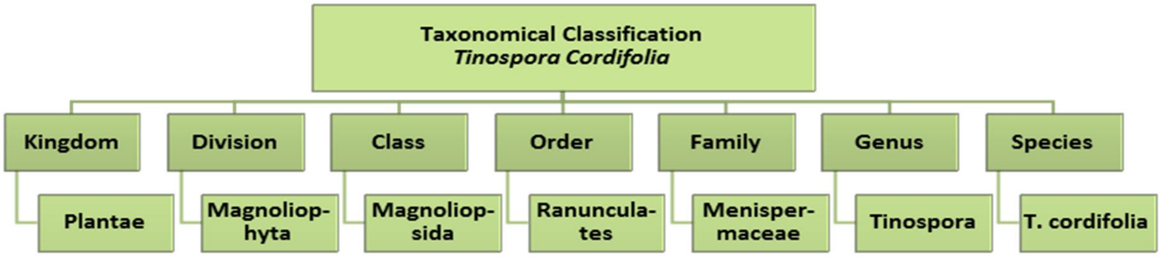

Fig. 1. Taxonomical Classification of *Tinospora Cordifolia* plant.

Only the tropics of the Indian subcontinent are home to the Menispermaceae herbaceous vine known as Tinospora Cordifolia, often referred to as gurjo, heart-leaved moonseed, guduchi, or giloy [17]. It is a substantial deciduous climbing shrub that has several long, twining branches and a broad distribution. Long petioles are found along with simple, alternating exstipulate leaves. Guduchi, an Indian medicinal plant, has been used for many years in Ayurvedic formulas to treat a range of diseases. This plant has been used to cure a variety of ailments, including general weakness, impotence, gout, fever, diarrhea, dyspepsia, gonorrhea, skin disorders, viral hepatitis, anemia and secondary syphilis. In compound formulations, guduchi is used medically to treat rheumatoid arthritis, diabetes, and jaundice. The root is considered to be a strong emetic and is used to alleviate intestinal obstruction [18-20]. Tinospora cordifolia's aerial parts, roots, and whole plant have produced a wide range of isolated compounds. Alkaloids (berberine, tinospporin, choline, isocolumbin, palmitine, tembetarine, etc.), steroids, diterpenoid lactones, and glycosides are some of the main components [21-22].

III. MATERIAL AND METHODS

A. Preparation of Stem and Leaves Extract

The Tinospora Cordifolia plant's newly harvested stem and leaves were air dried at room temperature before being processed into a powder. The dried stems and leaves of Tinospora Cordifolia are refluxed in a soxhlet unit with ethanol solvent and heated for the appropriate amount of time to get the stem and leaf extract.

B. Metal Used

For each experiment, copper coupons were utilized. Copper metal specimens were formulated by cutting a sheet of pure copper (99%) into squares coupons of 2.5 cm × 2.5 cm, each with a tiny hole at the top edge measuring about 2 mm in diameter. Each coupon was thoroughly cleaned and degreased before being polished to a high sheen.

C. Chemicals Used

Using analytical-grade reagent (98% H_2SO_4, 36% HCl), different concentration solutions of H_2SO_4 and HCl (i.e., 0.5N, 1N, 2N, and 3N) were produced in double distillation water and utilized for corrosion investigations. The ethanol solvent was used to make inhibitor solutions with various concentrations, including 0.2%, 0.4%, 0.6% and 0.8%.

D. Methods

1) Weight Loss Method

Each specimen was put into a beaker with 50 mL of the test solution and suspended by a V-shaped glass hook constructed of fine capillaries while at room temperature. After the proper exposure, test specimens were washed with running water and dried with a hot air dryer. Double trials were conducted in each instance, and the average amount of weight loss or reduction was calculated. Using this equation, the percentage inhibition efficiency was estimated [23–25].

$$\eta\% = \left[\frac{(\Delta W_u - \Delta W_i)}{\Delta W_u}\right] \times 100$$

Where the weight loss of the metal in the presence and absence of the inhibitor solution, respectively, is expressed as ΔW_u and ΔW_i. The following formulas were used to determine [26-27] the degree of surface coverage (θ):

$$\theta=\left[\frac{(\Delta W_u-\Delta W_i)}{\Delta W_u}\right]$$

The corrosion rate (CR), measured in mm/yr (millimeter per year), was expressed [28] as follow:

$$\text{Corrosion rate (mm/yr.)} = \frac{(\Delta W\times 87.6)}{(A\times T\times d)}$$

Where ΔW is the specimen's weight loss in mg, A is its exposure area in square centimeters (cm^2), T is its exposure period in hours, and d is its density in grams per cubic centimeter (g/cm^3).

2) Thermometric Method

This method involved immersing a single specimen with a surface area of 13 cm^2 in a insulated reaction chamber containing a 50 mL acid solution at a starting temperature of 301K in order to measure the degree of inhibition. However, there were no discernible temperature changes with 0.5N H_2SO_4 and HCL. As well as in the absence and presence of inhibitors at varied concentrations of 0.2%, 0.4%, 0.6% and 0.8%., experiments were carried out in acid solutions of 1N, 2N, and 3N. The test solution in the beaker was completely filled with the specimen and thermometer bulb. The beaker was kept in a space that was thermally insulated. At intervals of five minutes, temperature variations were measured using a thermometer with a precision of 0.1 k. The temperature increased steadily at first before increasing swiftly and reaching its highest point. Then the temperature was measured at its peak[33-39].

The reaction number, or RN (Kmin-1), is computed as follows [29] :

$$RN = \frac{T_m - T_i}{t}$$

where T_m = solution's maximum temperature.
T_i = solution's initial temperature.
t = amount of time (in minutes) needed to reach the highest (max.) temperature.

The calculation for percentage inhibition efficacy is as follows [30-32]:

$$\eta\% = \frac{(RN_f - RN_i)}{RN_f} \times 100$$

where RN_f= Reaction Number in uninhibited solution.
RN_i= Reaction Number in the inhibited solution.

IV. RESULTS AND DISCUSSION

Weight loss and thermometric methods were used to examine the corrosion rate of copper metal in sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) solutions of various strengths in the absence and presence of additives (KI and K_2SO_4) and plant stem and leaf extracts from Tinospora Cordifolia at a temperature of 301 K. Percentage inhibition efficiencies were calculated using both techniques. The data for weight loss, percentage inhibition efficiency, corrosion rate, and surface coverage for copper metal in 0.5N, 1N, 2N, and 3N sulphuric and hydrochloric acid solutions with varying inhibitor concentrations (0.2% to 0.8%) are shown in Tables 1,2, 3, and 4, respectively, in both the absence and presence of an additives (KI & K_2SO_4). The related graphs in Figures 1a–b, 2a–b, 3a–b, and 4a–b, show the efficiency of inhibition and the Langmuir adsorption isotherm. In order to determine the reaction number and percentage of inhibition efficiency for stem and leaf extracts at different concentrations (0.2% to 0.8%) in 1N, 2N, and 3N H_2SO_4 and HCl acid solutions, the values in tables 5 and 6 were employed. The corresponding graphs are shown in Figs. 5 and 6, respectively. However, at 0.5N H_2SO_4 and HCl, there were no appreciable temperature changes.

The tables above demonstrate that as inhibitor concentration grows, so does its ability to inhibit .The maximal inhibitory efficiency for stem extract at maximum inhibitor concentrations of 0.8% was 96.54% and 99.19% in 0.5 N H_2SO_4 and 95.26% & 97.78% in 0.5 N HCl, respectively, in the absence and presence of additives (KI & K_2SO_4). Similar to this, the effectiveness of the leaf extract's inhibition was 95.37% and 97.84% in 0.5 N H_2SO_4 and 94.15% and 96.92% in 0.5 N HCl, at a maximum inhibitor concentration of 0.8% in the absence and addition, respectively, of additives (KI & K_2SO_4).

Based on the findings, stem extract suppresses H_2SO_4 and HCl more potently than leaf extract. With an increase in inhibitor concentration (from 0.2% to 0.8%), surface coverage (θ) rises. As inhibitor concentrations grow, the values of log (θ/(1-θ) increase linearly, indicating that the inhibitors follow the Langmuir adsorption isotherm or the chemisorption isotherm.

The current investigation discovered that the inhibitors (stem and leaf) were more effective at inhibiting the metal copper in H_2SO_4 acid HCl solutions when an additive (KI and K_2SO_4) was present than when the inhibitors (stem and leaf) were present alone. Synergistic effects are to blame for this. The combined action of the two chemicals is more potent on a metal surface than the combined actions of the two chemicals acting separately or concurrently. When organic inhibitors are used to prevent metallic corrosion, adsorption is a key factor. The effectiveness of inhibitors, measured as the percentage decrease in corrosion rate, can be qualitatively correlated to the amount of adsorbed inhibitors on the metal surface. It is believed that corrosion reactions are hindered from occurring at the active sites of the metal surface where adsorbed inhibitor species are present, whereas corrosion reactions are assumed to typically occur at the inhibitor-free regions of the surface. The percentage of the surface covered by adsorption inhibitors determines how effective the inhibition is, and vice versa.

Weight loss method:

Table I

Weight Loss (Δw), Percentage inhibition efficiency (η%) for copper in 0.5N, 1N, 2N and 3N H_2SO_4 with inhibitor of stem and leaves extract

Temperature : 301°K ± 0.1°K　　Area of Specimen : 13 cm^2　　Time of Exposure : 168 hrs

Inhibitors Concentration	0.5N H_2SO_4 (168 hrs)					1N H_2SO_4 (120 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
	Stem					Stem				
Uninhibited	1.6220			0.00726		1.625			0.010184	
0.2	0.163	0.8995	89.95	0.00073	0.95783	0.205	0.8738	87.38	0.00128	0.84035
0.4	0.142	0.9136	91.24	0.00062	1.02424	0.158	0.9027	90.27	0.00099	0.96743
0.6	0.104	0.9358	93.58	0.00046	1.16364	0.108	0.9335	93.35	0.00067	1.14729
0.8	0.055	0.9654	96.54	0.00024	1.44563	0.058	0.9643	96.43	0.00036	1.43154
	Leaves					Leaves				
0.2	0.188	0.8840	88.40	0.00084	0.88199	0.221	0.8640	86.40	0.00138	0.80297
0.4	0.160	0.9013	90.13	0.00072	0.96055	0.175	0.8923	89.23	0.00109	0.91829
0.6	0.121	0.9254	92.54	0.00054	1.09359	0.125	0.9230	92.30	0.00078	1.07871
0.8	0.075	0.9537	95.37	0.00033	1.31383	0.095	0.9415	94.15	0.00059	1.20666

Inhibitors Concentration	2N H_2SO_4 (72 hrs)					3N H_2SO_4 (36 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
	Stem					Stem				
Uninhibited	1.630			0.01702		1.628			0.03401	
0.2	0.238	0.8539	85.35	0.00248	0.76675	0.255	0.8433	84.33	0.00532	0.73091
0.4	0.186	0.8858	88.58	0.00194	0.88966	0.202	0.8759	87.59	0.00421	0.84868
0.6	0.135	0.9171	91.71	0.00141	1.04386	0.140	0.9140	91.40	0.00292	1.02644
0.8	0.078	0.9521	95.21	0.00081	1.29834	0.110	0.9324	93.24	0.00229	1.13965
	Leaves					Leaves				
0.2	0.270	0.8343	83.43	0.00282	0.70199	0.288	0.8230	82.30	0.00601	0.66742
0.4	0.225	0.8619	86.19	0.00235	0.79526	0.235	0.8556	85.56	0.00490	0.77270
0.6	0.175	0.8926	89.26	0.00182	0.91965	0.190	0.8832	88.32	0.00396	0.87861
0.8	0.108	0.9337	93.37	0.00112	1.14869	0.135	0.9152	91.52	0.00288	1.03312

Table II

Weight Loss (Δw), Percentage inhibition efficiency (η%) for copper in 0.5N, 1N, 2N and 3N H_2SO_4 with inhibitor of stem and leaves extract with additive K_2SO_4

Temperature : $301^oK \pm 0.1^oK$ Area of Specimen : 13 cm^2

Inhibitors Concentration	0.5N H_2SO_4 + 0.5N K_2SO_4 (168 hrs)					1N H_2SO_4 + 1N K_2SO_4 (120 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
	Stem					Stem				
Uninhibited	1.6220			0.00726		1.625			0.010184	
0.2	0.122	0.9247	92.47	0.00054	1.08920	0.148	0.9089	90.89	0.00092	0.99899
0.4	0.086	0.9469	94.69	0.00038	1.25120	0.118	0.9273	92.73	0.00073	1.10568
0.6	0.038	0.9765	97.65	0.00017	1.61860	0.068	0.9581	95.81	0.00042	1.35919
0.8	0.013	0.9919	99.19	0.00006	2.08798	0.020	0.9876	98.76	0.00013	1.90115
	Leaves					Leaves				
0.2	0.149	0.9081	90.81	0.00066	0.99481	0.165	0.8984	89.84	0.00103	0.94657
0.4	0.115	0.9290	92.90	0.00051	1.11675	0.115	0.9292	92.92	0.00072	1.11807
0.6	0.085	0.9475	94.75	0.00038	1.25641	0.085	0.9476	94.76	0.00053	1.25729
0.8	0.035	0.9784	97.84	0.00015	1.65606	0.051	0.9686	96.86	0.00032	1.48921

Inhibitors Concentration	2N H_2SO_4 + 2N K_2SO_4 (168 hrs)					3N H_2SO_4 + 3N K_2SO_4 (120 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
	Stem					Stem				
Uninhibited	1.630			0.01702		1.628			0.03401	
0.2	0.180	0.8895	88.95	0.00188	0.90578	0.180	0.8894	88.94	0.00376	0.90534
0.4	0.118	0.9276	92.76	0.00123	1.10762	0.150	0.9078	90.78	0.00313	0.99325
0.6	0.084	0.9484	94.84	0.00087	1.26434	0.100	0.9385	93.85	0.00208	1.18355
0.8	0.036	0.9779	97.79	0.00037	1.64590	0.056	0.9656	96.56	0.00116	1.44823
	Leaves					Leaves				
0.2	0.213	0.8693	86.93	0.00222	0.82289	0.246	0.8488	84.88	0.00513	0.74925
0.4	0.165	0.8987	89.87	0.00172	0.94800	0.196	0.8796	87.96	0.00409	0.86365
0.6	0.120	0.9263	92.63	0.00125	1.09928	0.119	0.9269	92.69	0.00248	1.10312
0.8	0.068	0.9582	95.82	0.00071	1.36027	0.083	0.9490	94.90	0.00173	1.26969

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Table III
Weight Loss (Δw), Percentage inhibition efficiency (η%) for Copper in 0.5N, 1N, 2N, 3N HCl with inhibitor of stem and leaves extract

Temperature : $301^oK \pm 0.1^oK$ Area of Specimen : 13 cm^2

Inhibitors Concentration	0.5N HCl (48 hrs)					1N HCl (24 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
Stem						Stem				
Uninhibited	1.625			0.02546		1.628			0.05101	
0.2	0.208	0.8720	87.20	0.00325	0.83330	0.239	0.8531	85.31	0.00748	0.76397
0.4	0.157	0.9033	90.33	0.00245	0.97040	0.191	0.8826	88.26	0.00598	0.87609
0.6	0.127	0.9218	92.18	0.00198	1.07142	0.157	0.9035	90.35	0.00491	0.97140
0.8	0.077	0.9526	95.26	0.00120	1.30313	0.112	0.9312	93.12	0.00350	1.13145
Leaves						Leaves				
0.2	0.236	0.8547	85.47	0.00369	0.76954	0.269	0.8347	83.47	0.00842	0.70325
0.4	0.191	0.8824	88.24	0.00299	0.87525	0.223	0.8690	86.30	0.00698	0.79929
0.6	0.138	0.9150	91.50	0.00216	1.03200	0.189	0.8839	88.39	0.00592	0.88157
0.8	0.093	0.9427	94.15	0.00145	1.20664	0.135	0.9170	91.70	0.00423	0.99952

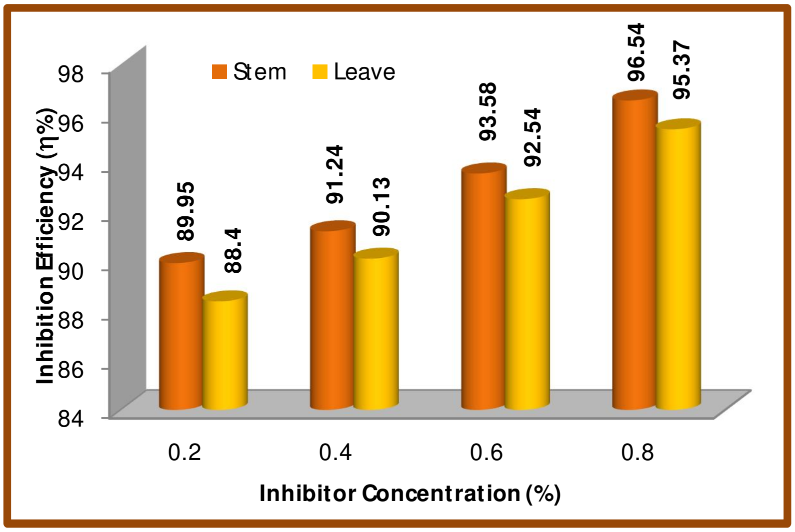
Inhibitors Concentration	2N HCl (10 hrs)					3N HCl (6 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
Stem						Stem				
Uninhibited	1.630			0.12258		1.622			0.20330	
0.2	0.272	0.8331	83.31	0.02045	0.69824	0.319	0.8033	80.33	0.03998	0.61107
0.4	0.224	0.8625	86.25	0.01684	0.79745	0.271	0.8329	83.29	0.03396	0.69761
0.6	0.174	0.8932	89.32	0.01308	0.92237	0.204	0.8742	87.42	0.02557	0.84193
0.8	0.128	0.9214	92.14	0.00962	1.06902	0.138	0.9149	91.49	0.01729	1.03144
Leaves						Leaves				
0.2	0.305	0.8128	81.28	0.02293	0.63767	0.351	0.7836	78.36	0.04399	0.55883
0.4	0.256	0.8429	84.29	0.01925	0.72959	0.288	0.8224	82.24	0.03609	0.66564
0.6	0.207	0.8730	87.30	0.01556	0.83721	0.236	0.8545	85.45	0.029581	0.76884
0.8	0.159	0.9024	90.24	0.01195	0.96594	0.172	0.8939	89.39	0.021559	0.92557

Table IV
Weight Loss (Δw) and Percentage inhibition efficiency (η%) for Copper in 0.5N, 1N, 2N and 3N HCl with inhibitor of stem and leaves extract in presence of additive (KI)

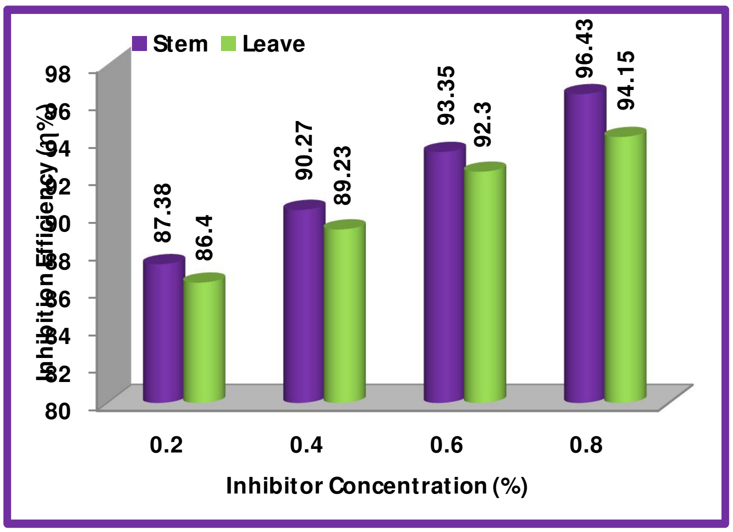
Temperature : $301^oK \pm 0.1^oK$ Area of Specimen : $13\ cm^2$

Inhibitors Concentration	0.5N HCl + 0.5 KI(48 hrs)					1N HCl + 1N KI (24 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
Stem						Stem				
Uninhibited	1.625			0.02546		1.628			0.05101	
0.2	0.168	0.8966	89.66	0.00263	0.93807	0.201	0.8765	87.65	0.00629	0.85108
0.4	0.116	0.9286	92.86	0.00181	1.11413	0.134	0.9176	91.76	0.00419	1.04672
0.6	0.083	0.9489	94.89	0.00130	1.26879	0.101	0.9379	93.79	0.00316	1.17906
0.8	0.036	0.9778	97.78	0.00056	1.64389	0.054	0.9668	96.68	0.00169	1.46419
Leaves						Leaves				
0.2	0.181	0.8886	88.86	0.00283	0.90182	0.230	0.8587	85.87	0.00720	0.78369
0.4	0.119	0.9267	92.67	0.00186	1.10183	0.172	0.8943	89.43	0.00538	0.92740
0.6	0.069	0.9575	95.75	0.00108	1.35274	0.151	0.9072	90.72	0.00473	0.99015
0.8	0.050	0.9692	96.92	0.00078	1.49786	0.080	0.9508	95.08	0.00250	1.28612

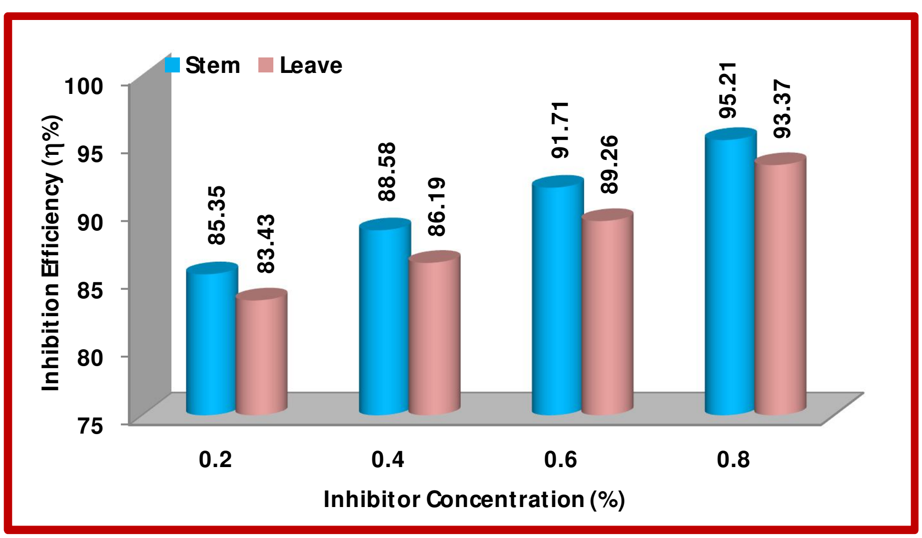
Inhibitors Concentration	2N HCl + 2N KI (10 hrs)					3N HCl + 3N KI (6 hrs)				
	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$	Δw	Surface Coverage(θ)	I.E. (η%)	Corrosion Rate(mm/yr)	$\log\left(\frac{\theta}{1-\theta}\right)$
Stem						Stem				
Uninhibited	1.630			0.12258		1.622			0.20330	
0.2	0.235	0.8558	85.58	0.01767	0.77340	0.251	0.8452	84.52	0.031461	0.73718
0.4	0.168	0.8969	89.69	0.01263	0.93948	0.216	0.8668	86.68	0.02707	0.81341
0.6	0.106	0.9349	93.49	0.00797	1.15718	0.150	0.9075	90.75	0.01880	0.99170
0.8	0.073	0.9552	95.52	0.00549	1.32881	0.103	0.9364	93.64	0.01291	1.16800
Leaves						Leaves				
0.2	0.250	0.8466	84.66	0.01880	0.74185	0.299	0.8156	81.56	0.03747	0.64571
0.4	0.187	0.8852	88.52	0.01406	0.88709	0.221	0.8637	86.37	0.02770	0.80186
0.6	0.136	0.9165	91.65	0.01022	1.04044	0.171	0.8945	89.45	0.021433	0.92832
0.8	0.086	0.9422	94.72	0.00646	1.25380	0.120	0.9260	92.60	0.015041	1.09737



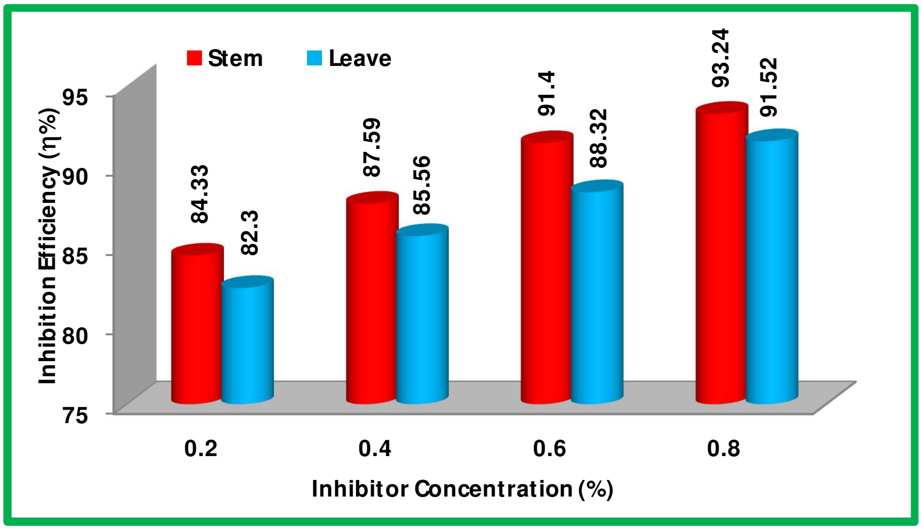
0.5N H_2SO_4 (168 hrs)



1N H_2SO_4 (120 hrs)

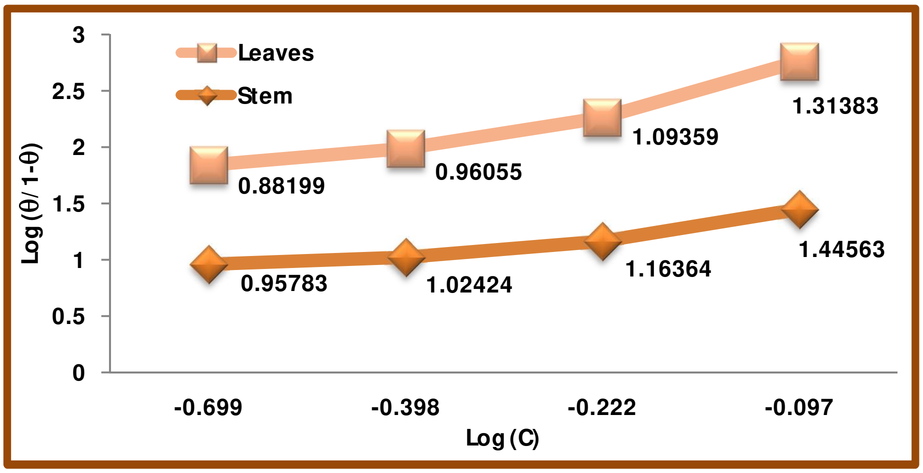


2N H_2SO_4 (72 hrs)

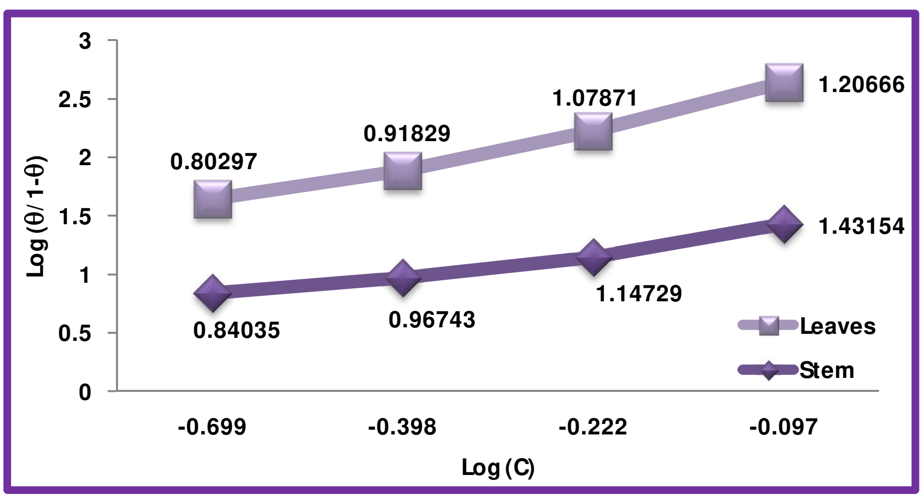


H_2SO_4 (36 hr

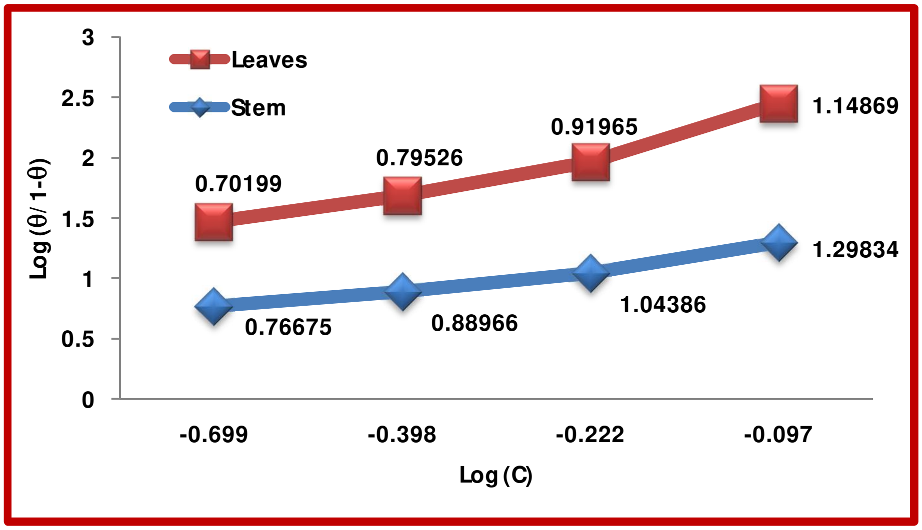
Figure 2(a) : Variation of Inhibition Efficiency (η%) for copper in 0.5N, 1N, 2N and 3N H_2SO_4 with inhibitor concentration of stem and leaves extract.



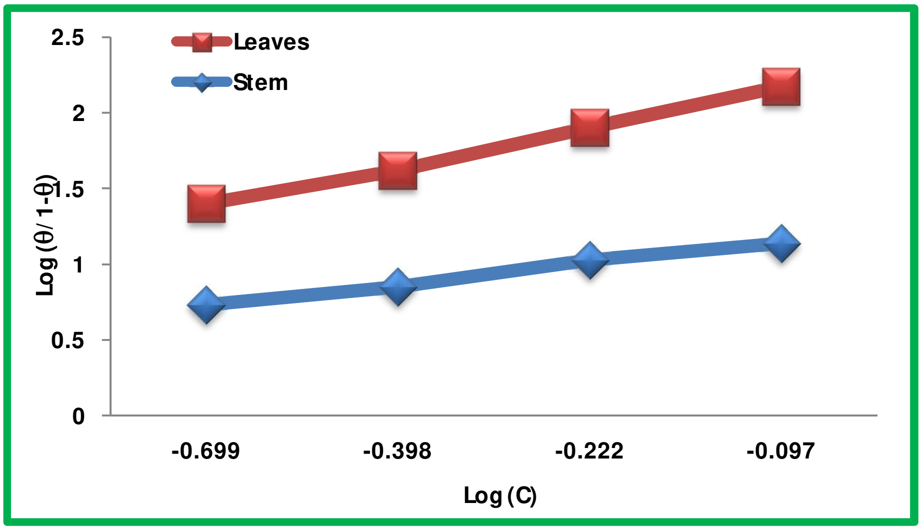
0.5N H_2SO_4 (168 hrs)



1N H_2SO_4 (120 hrs)

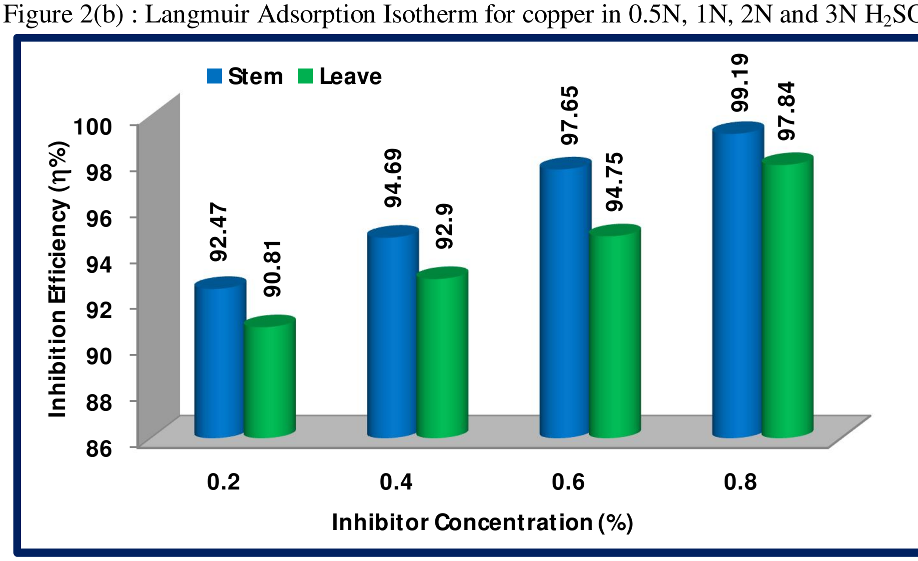


2N H_2SO_4 (72 hrs)

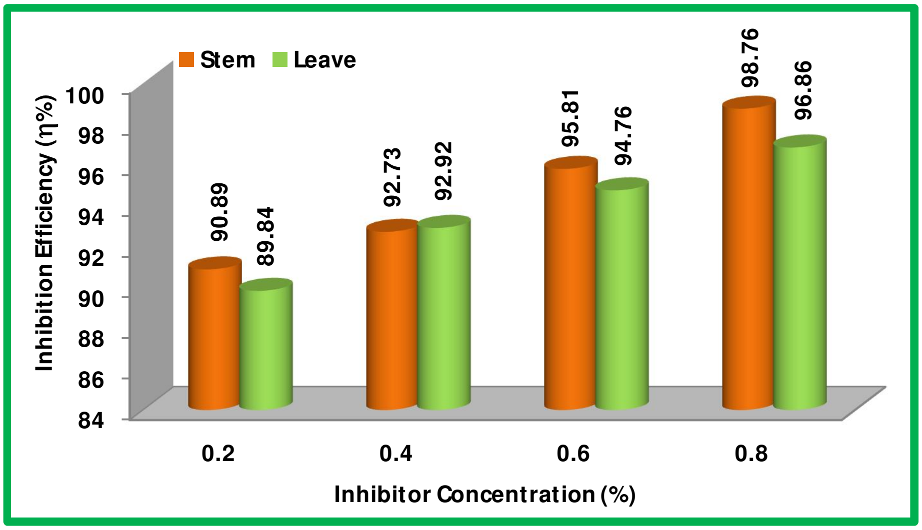


3N H_2SO_4 (36 hrs)

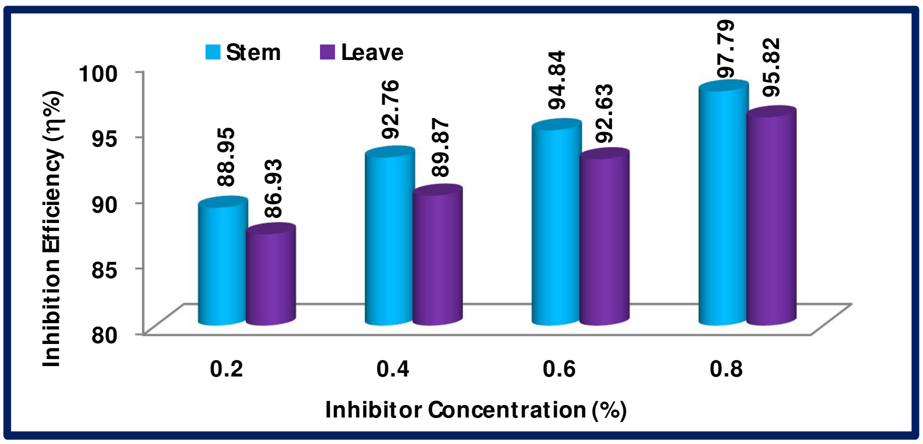
Figure 2(b) : Langmuir Adsorption Isotherm for copper in 0.5N, 1N, 2N and 3N H_2SO_4



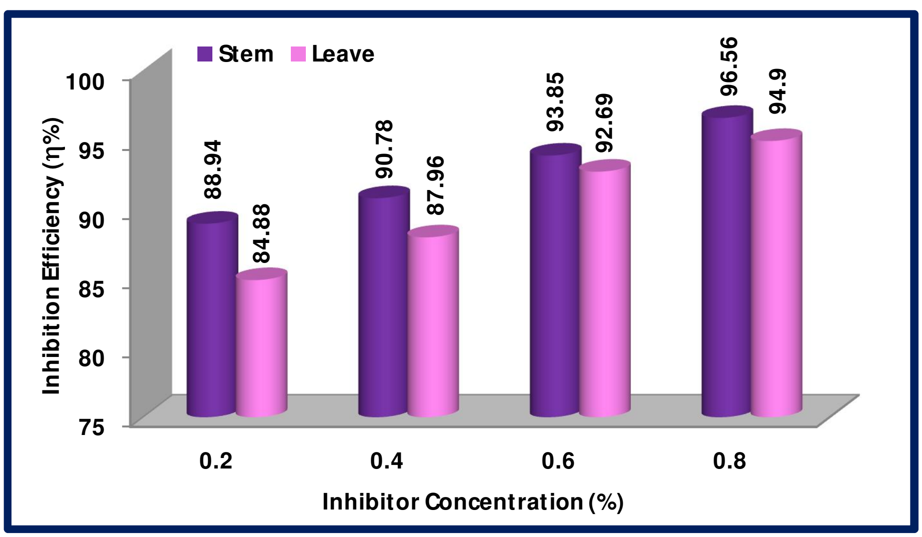
0.5N H_2SO_4 + 0.5N K_2SO_4 (168 hrs)



1N H_2SO_4 + 1N K_2SO_4 (120 hrs)

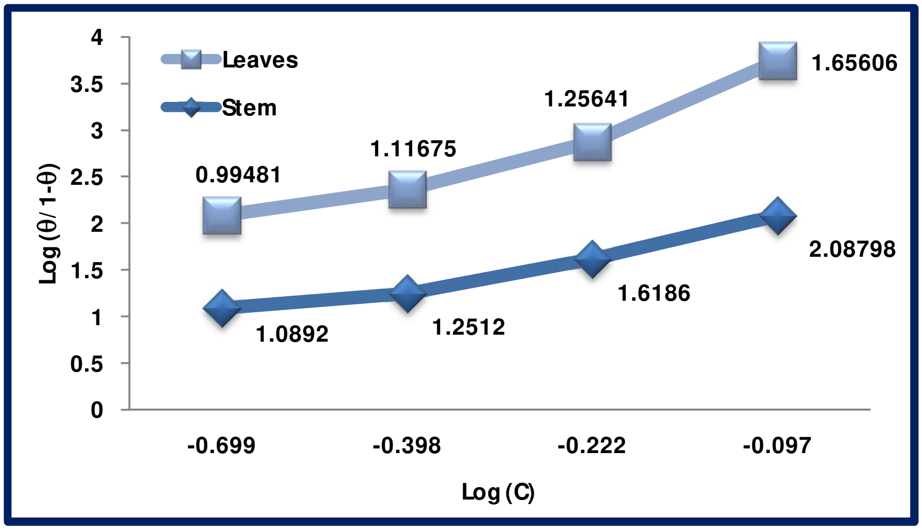


2N H_2SO_4 + 2N K_2SO_4 (168 hrs)

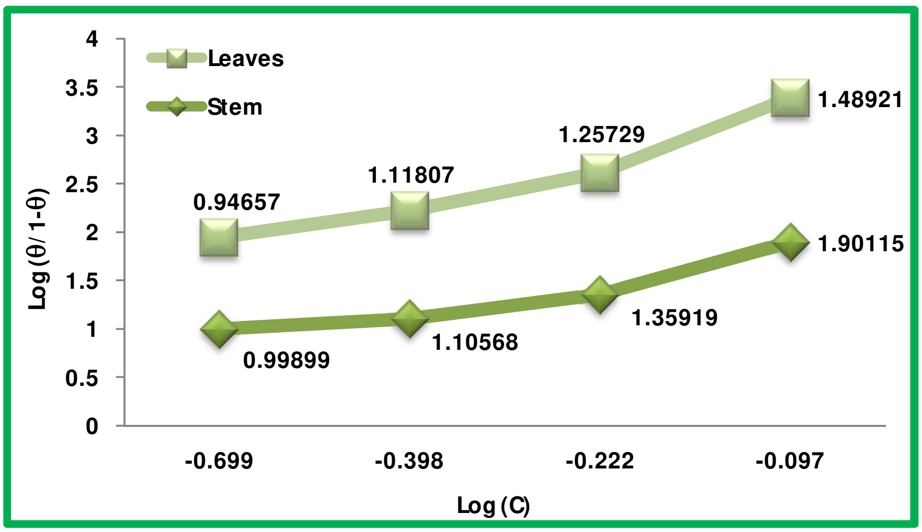


3N H_2SO_4 + 3N K_2SO_4 (120 hrs)

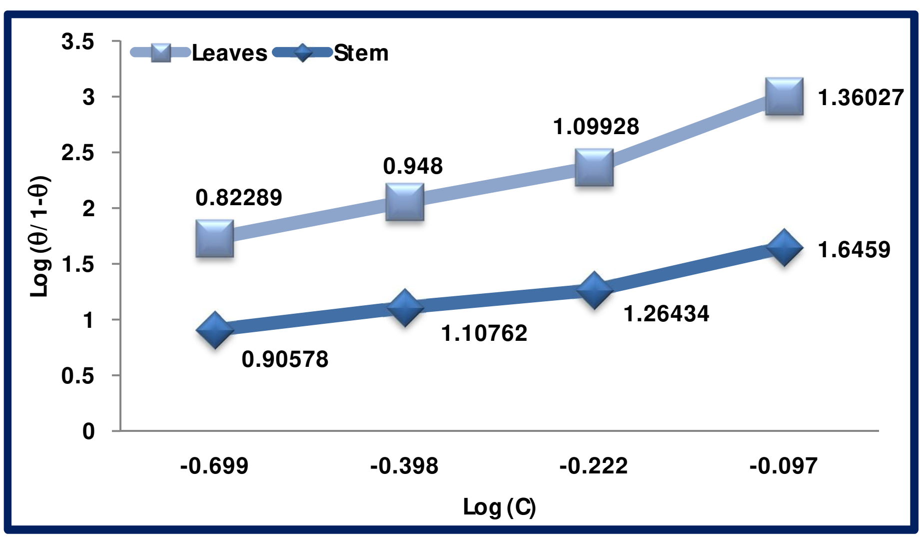
Figure 3(a) : Variation of Inhibition Efficiency for copper in 0.5N, 1N, 2N & 3N H_2SO_4 with inhibitor conc. of stem & leaves extract in presence of additive K_2SO_4.



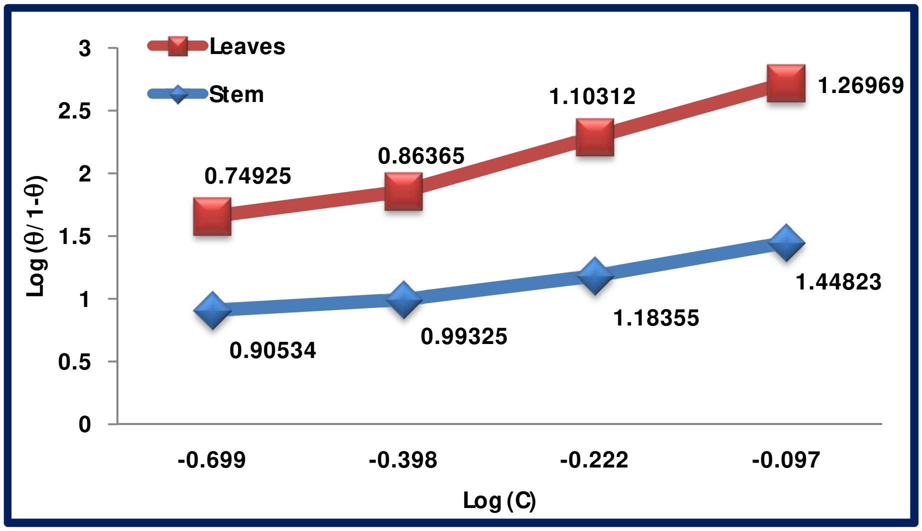
0.5N H_2SO_4 + 0.5N K_2SO_4 (168 hrs)



1N H_2SO_4 + 1N K_2SO_4 (120 hrs)

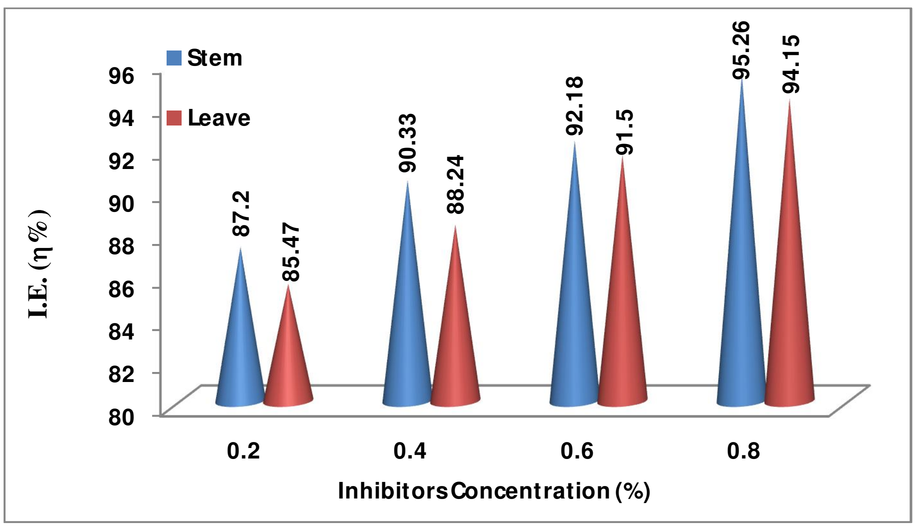


2N H_2SO_4 + 2N K_2SO_4 (168 hrs)

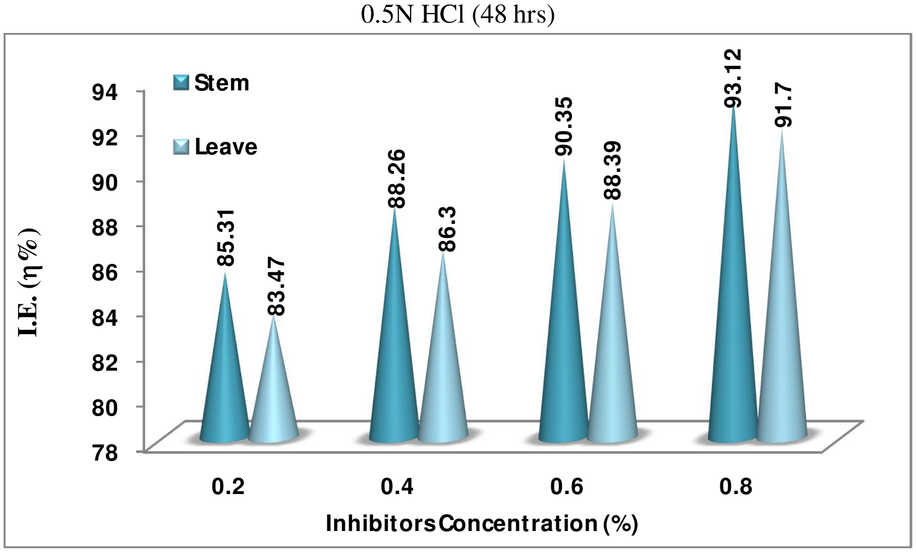


$3N\ H_2SO_4 + 3N\ K_2SO_4$ (120 hrs)

Figure 3(b) : Langmuir Adsorption Isotherm for copper in 0.5N, 1N, 2N & 3N H_2SO_4 in presence of additive K_2SO_4.



0.5N HCl (48 hrs)



1N HCl (24 hrs)

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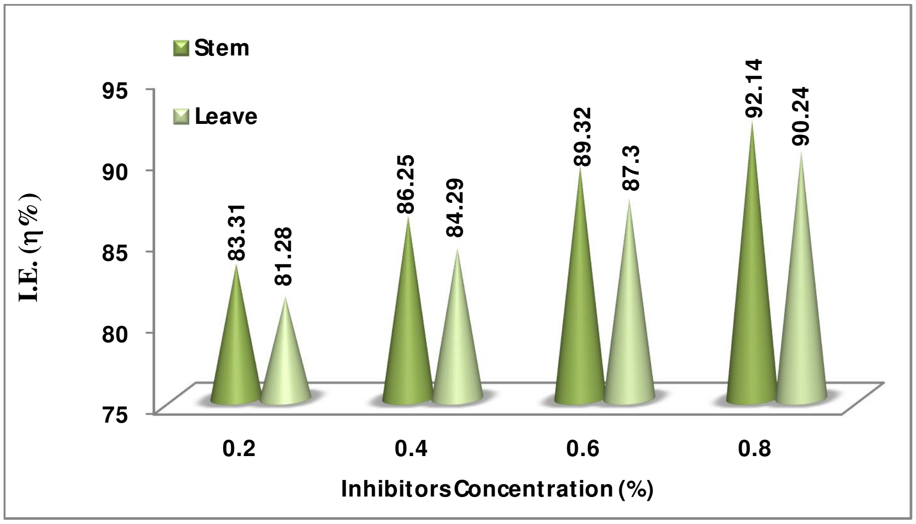
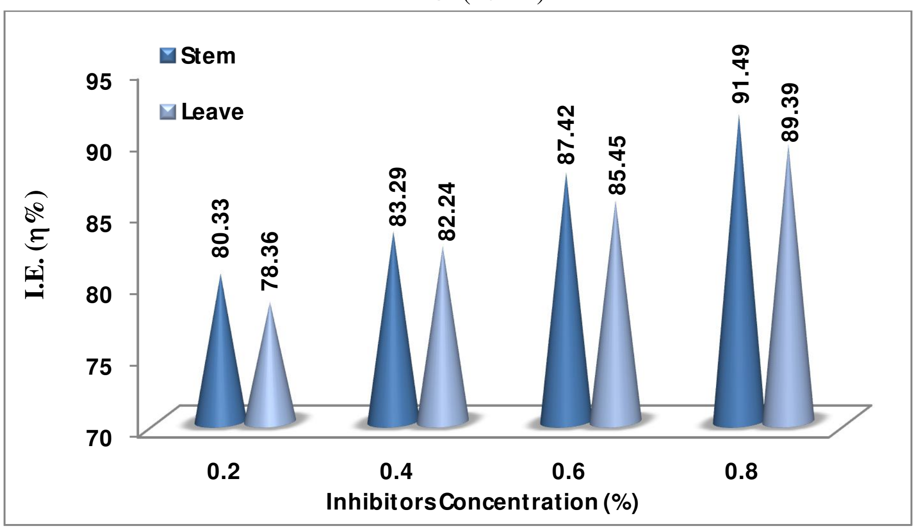
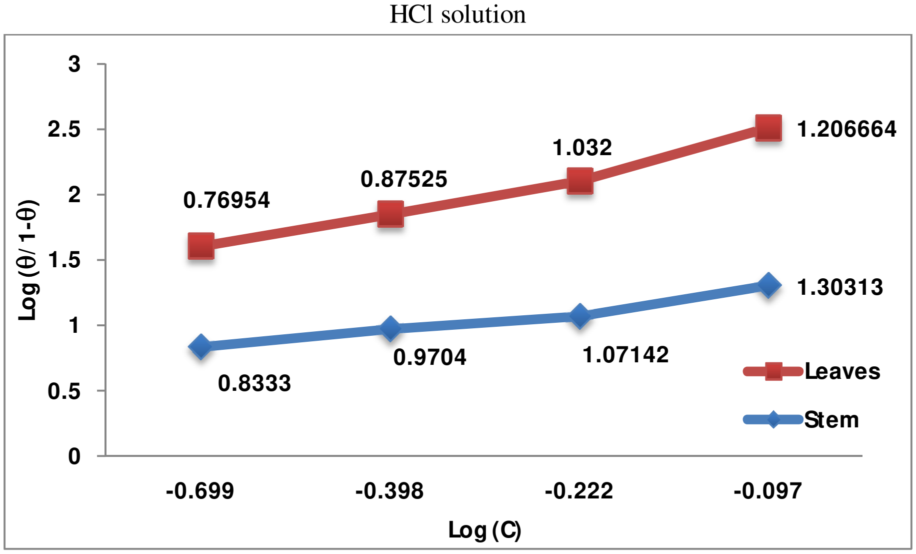


2N HCl (10 hrs)

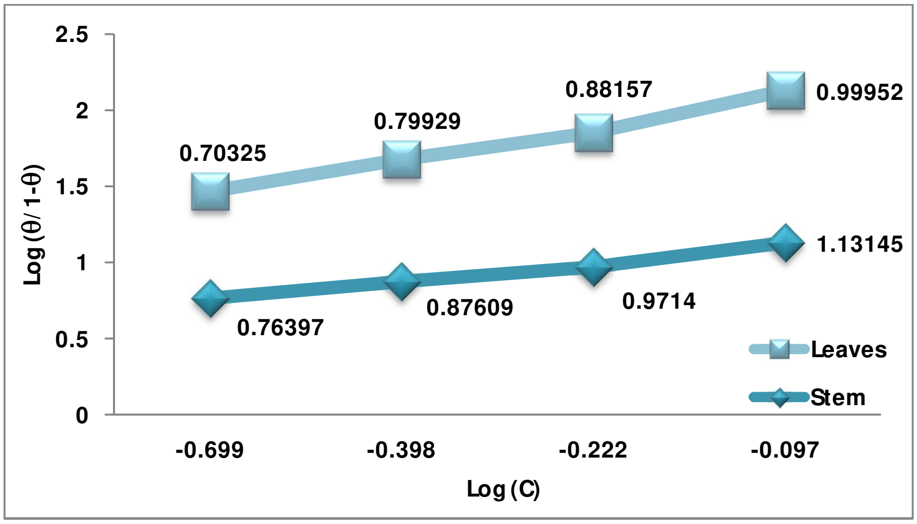


3N HCl (6 hrs)

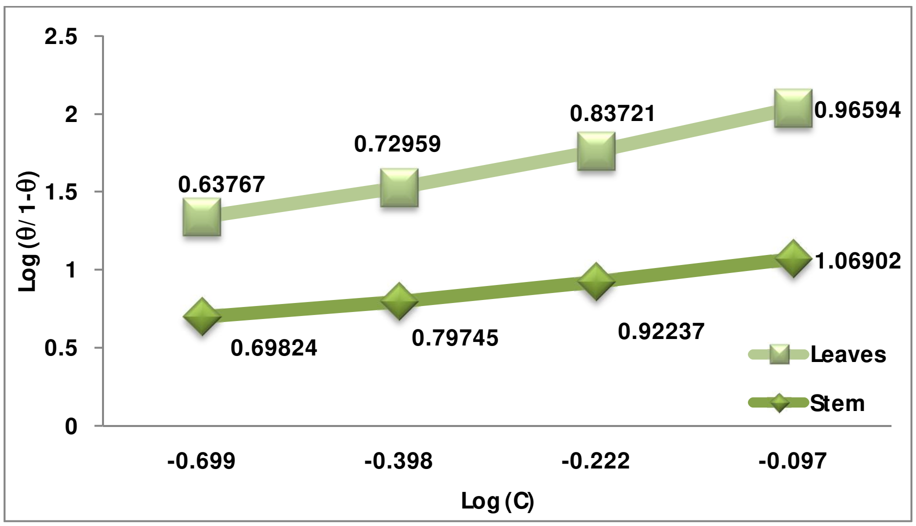
Figure 4(a) : Variation of Inhibition Efficiency with Concentration of Stem and Leaves extracts for Copper in 0.5N, 1N, 2N and 3N HCl solution



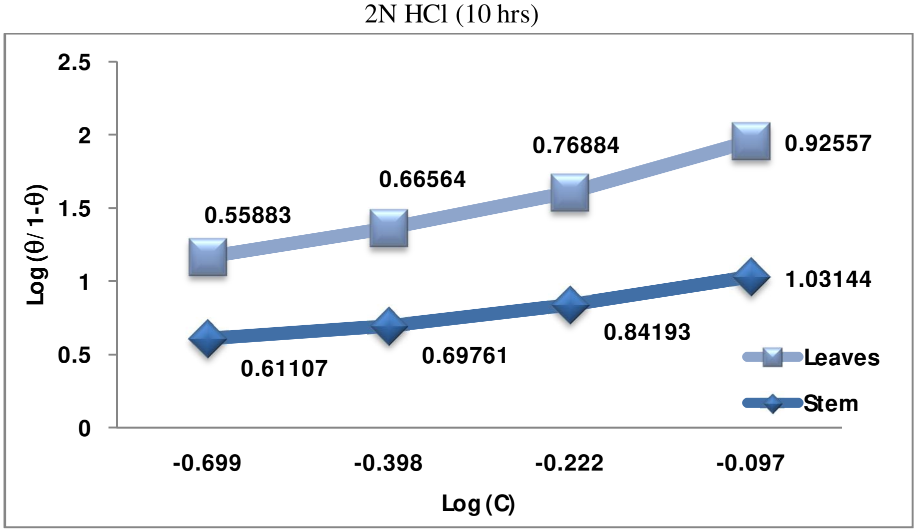
0.5N HCl (48 hrs)



1N HCl (24 hrs)

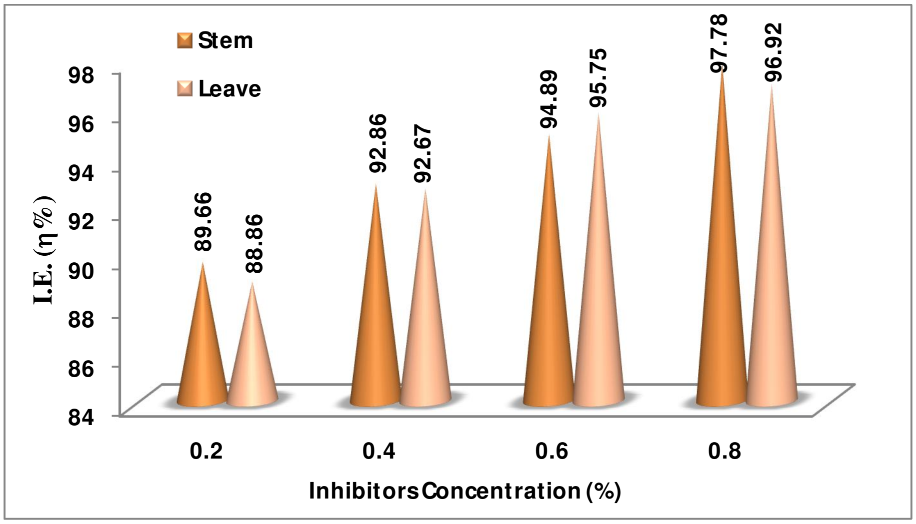


2N HCl (10 hrs)

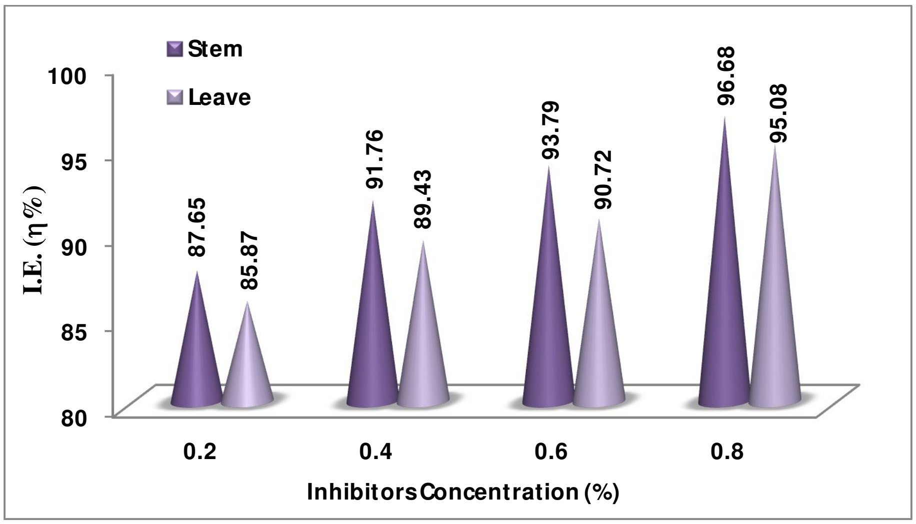


3N HCl (6 hrs)

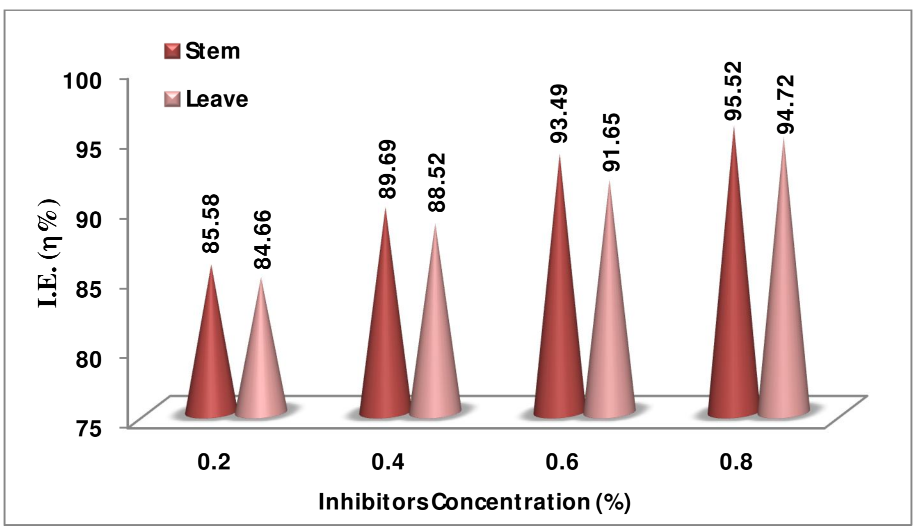
Figure 4(b) : Langmuir Adsorption Isotherm for Copper in 0.5N, 1N, 2N and 3N HCl solution



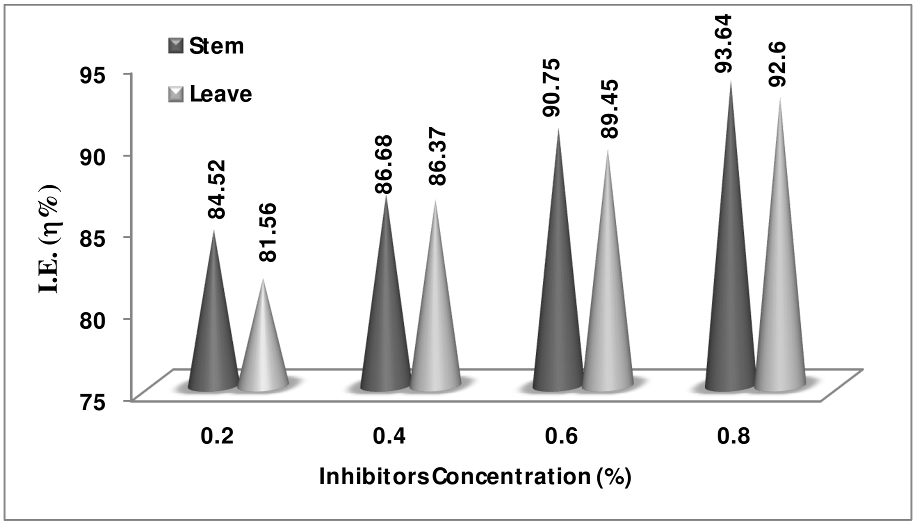
0.5N HCl + 0.5 KI (48 hrs)



1N HCl + 1N KI (24 hrs)

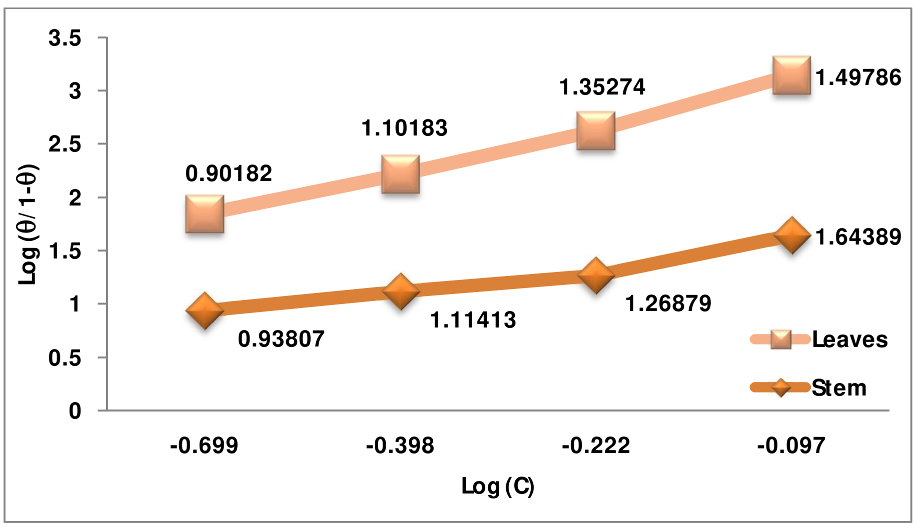


2N HCl + 2N KI (10 hrs)

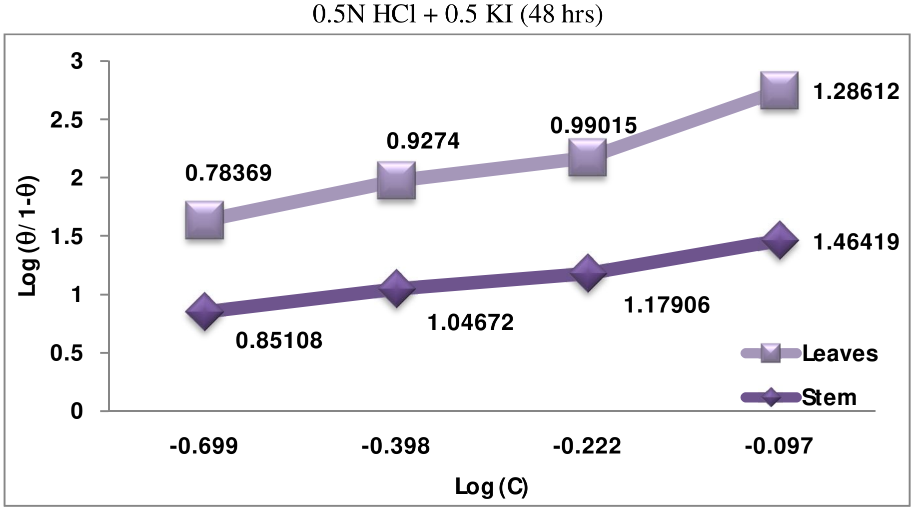


3N HCl + 3N KI (6 hrs)

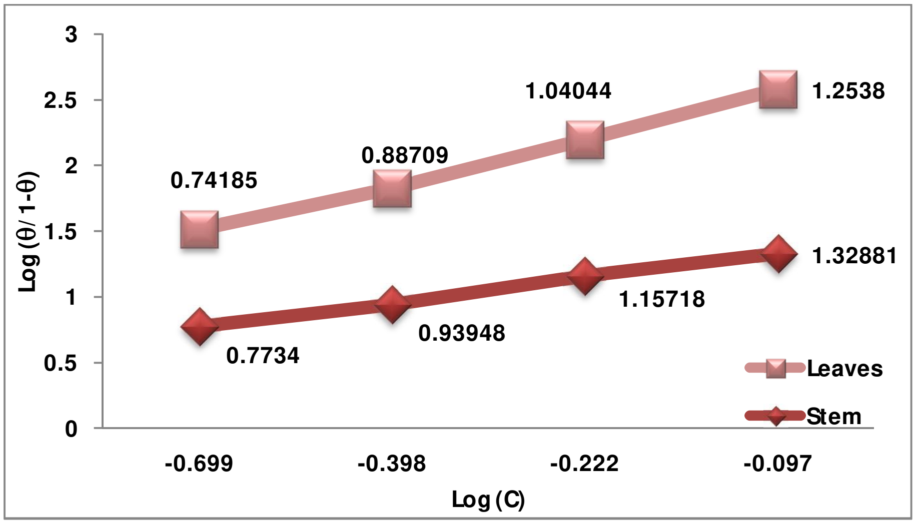
Figure 5(a) : Variation of Inhibition Efficiency with Concentration of Stem & Leaves extracts for Copper in 0.5N, 1N, 2N & 3N HCl in presence of additive (KI)



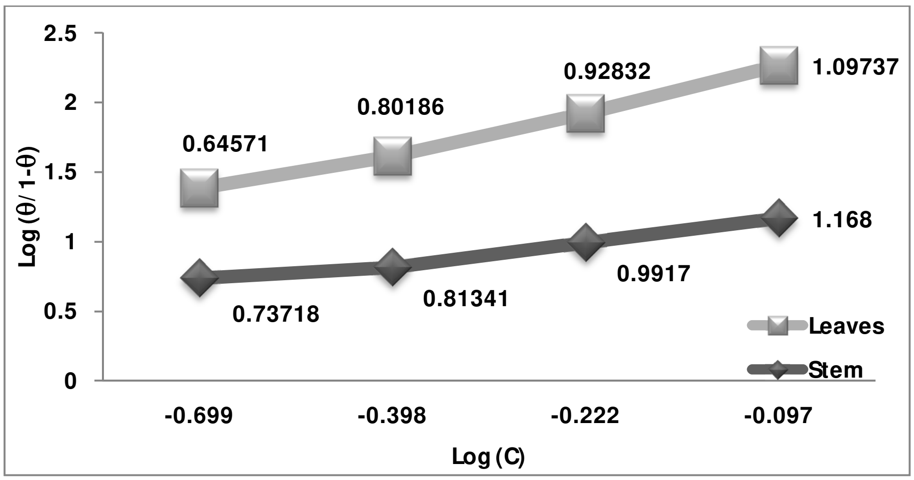
0.5N HCl + 0.5 KI (48 hrs)



1N HCl + 1N KI (24 hrs)



2N HCl + 2N KI (10 hrs)



3N HCl + 3N KI (6 hrs)

Figure 5(b) : Langmuir Adsorption Isotherm for Copper in 0.5N, 1N, 2N & 3N HCl in presence of additive (KI)

A. *Thermometric Method*

Table V

Reaction Number (RN) and Inhibition Efficiency (η%) for copper in 1N, 2N and 3N H_2SO_4 with inhibitor of stem and leaves extract

Temperature : $301^oK \pm 0.1^oK$ Area of Specimen : 13 cm^2

Inhibitor Concentration	1N H_2SO_4		2N H_2SO_4		3N H_2SO_4		1N H_2SO_4 +1N K_2SO_4		2N H_2SO_4 +2N K_2SO_4		3N H_2SO_4 +3N K_2SO_4	
	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)
Stem												
Uninhibited	0.3652		0.5628		0.7346		0.3652		0.5628		0.7346	
0.2	0.1156	68.34	0.1946	65.42	0.2680	63.51	0.1041	71.49	0.1715	69.52	0.2440	66.78
0.4	0.1012	72.28	0.1788	68.23	0.2464	66.45	0.0889	75.65	0.1555	72.37	0.2240	69.50
0.6	0.0856	76.56	0.1612	71.35	0.2158	70.62	0.0782	78.58	0.1384	75.40	0.1930	73.68
0.8	0.0751	79.43	0.1320	76.54	0.1885	74.33	0.0644	82.36	0.1083	80.75	0.1552	78.87
Leaves												
0.2	0.1230	66.31	0.2055	63.48	0.2810	61.74	0.1149	68.53	0.1924	65.81	0.2538	65.45
0.4	0.1115	69.46	0.1899	66.25	0.2604	64.55	0.0998	72.67	0.1765	68.63	0.2395	67.39
0.6	0.0963	73.63	0.1667	70.38	0.2318	68.44	0.0850	76.72	0.1487	73.57	0.2082	71.65
0.8	0.0831	77.24	0.1429	74.60	0.1998	72.80	0.0714	80.44	0.1215	78.41	0.1702	76.83

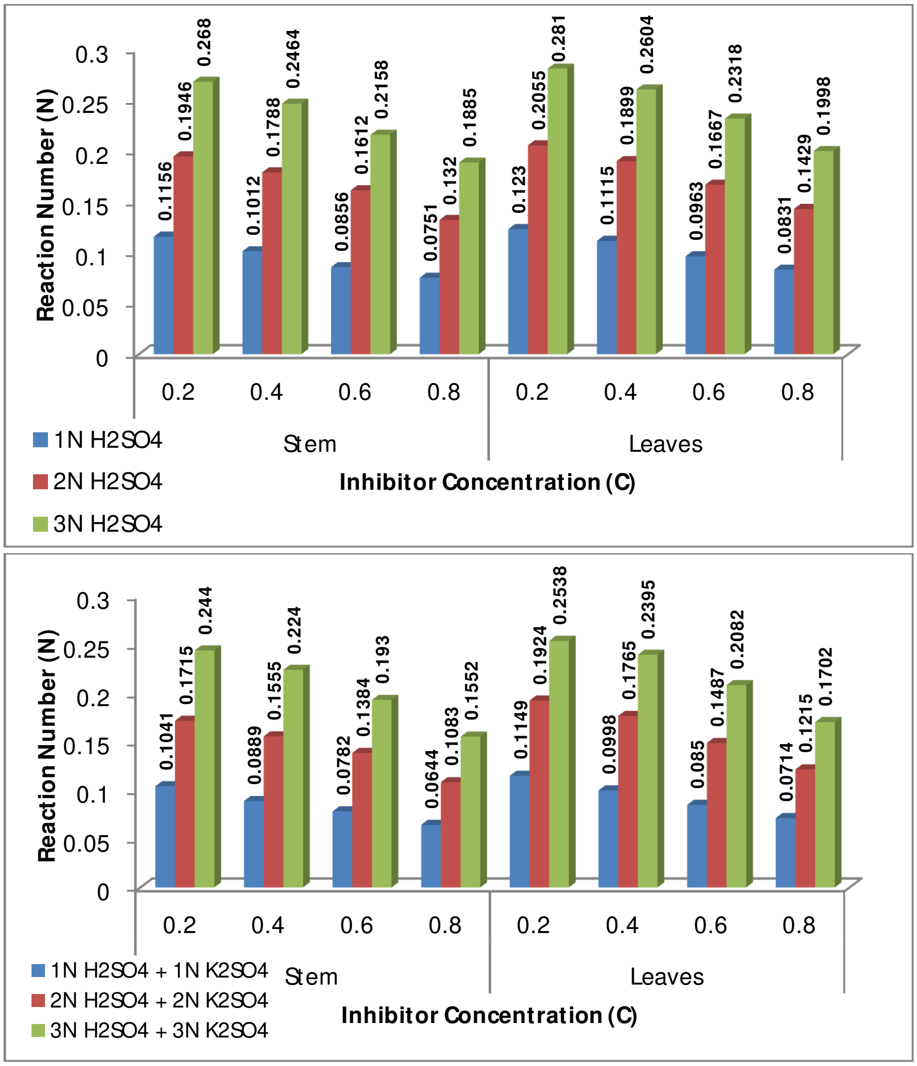


Figure 6 : Variation of Reaction Number (RN) with Inhibitor Concentration of Stem and Leaves extracts for Copper in 1N, 2N and 3N H_2SO_4

Table VI

Reaction Number (RN) and Inhibition Efficiency (η%) for copper in 1N, 2N and 3N HCl with inhibitor of stem and leaves extract

Temperature : 301°K ± 0.1°K Area of Specimen : 13 cm^2

Inhibitor Concentration	1N HCl		2N HCl		3N HCl		1N HCl+ 1N KI		2N HCl + 2N KI		3N HCl + 3N KI	
	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)	RN	I.E.(η%)
Stem												
Uninhibited	0.6845		0.8236		0.9754		0.6845		0.8236		0.9754	
0.2	0.2239	67.28	0.2771	66.35	0.3469	64.43	0.1947	71.55	0.2576	68.72	0.3248	66.70
0.4	0.2019	70.50	0.2531	69.26	0.3195	67.24	0.1796	73.76	0.2262	72.53	0.2937	69.88
0.6	0.1891	72.37	0.2343	71.55	0.2986	69.38	0.1622	76.30	0.2101	74.49	0.2738	71.92
0.8	0.1668	75.63	0.2190	73.40	0.2678	72.54	0.1462	78.64	0.1906	76.85	0.2378	75.62
Leaves												
0.2	0.2314	66.19	0.2833	65.60	0.3553	63.57	0.2195	67.93	0.2656	67.75	0.3321	65.95
0.4	0.2173	68.25	0.2690	67.33	0.3380	65.34	0.2082	69.58	0.2517	69.43	0.3155	67.65
0.6	0.1954	71.45	0.2596	68.52	0.3200	67.19	0.1803	73.65	0.2332	71.68	0.2850	70.78
0.8	0.1826	73.32	0.2436	70.42	0.2964	69.61	0.1679	75.47	0.2149	73.90	0.2686	72.46

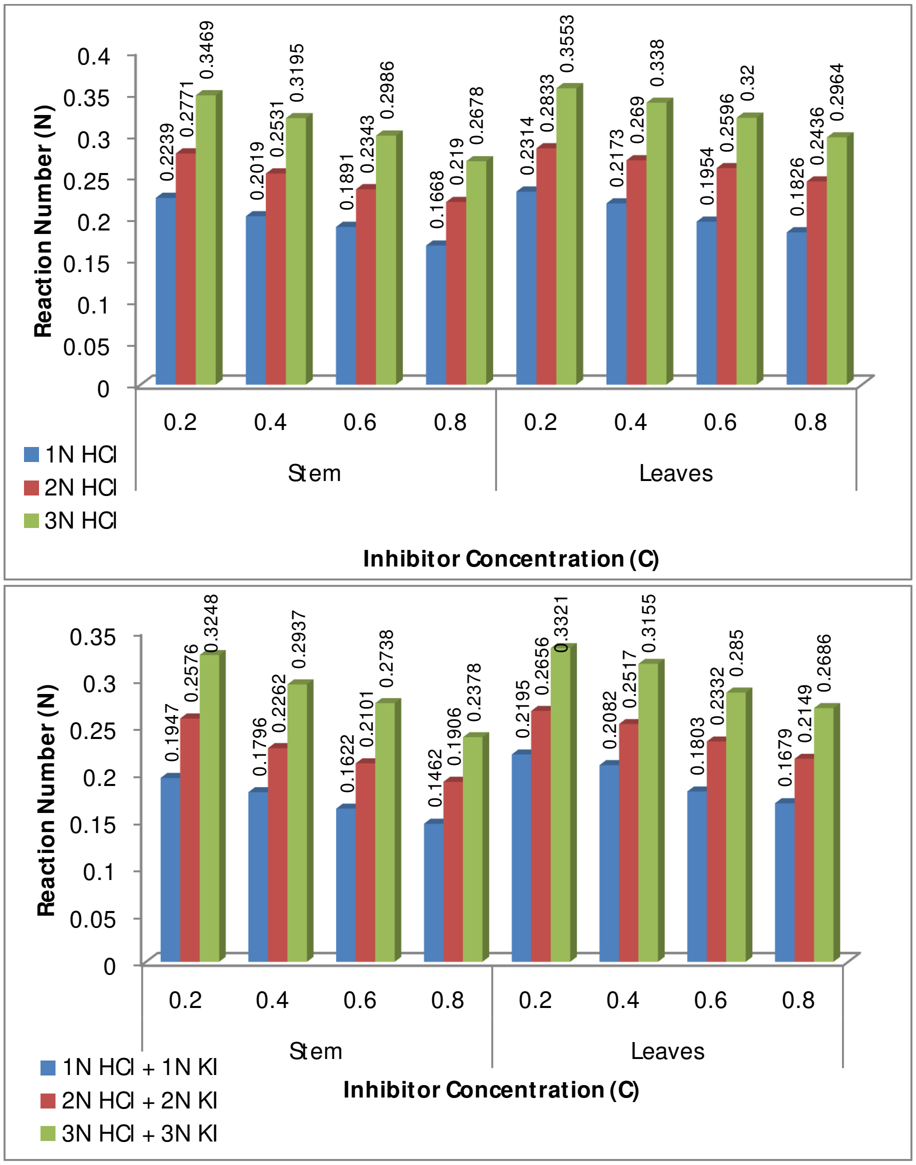


Figure 7 : Variation of Reaction Number (RN) with Inhibitor Concentration of Stem and Leaves extracts for Copper in 1N, 2N and 3N HCl

V. CONCLUSION

Tinospora Cordifolia stem and leaf extract has been shown to be an efficient corrosion inhibitor on copper in both the absence and presence of additives (KI & K_2SO_4) at varied concentrations of sulphuric (H_2SO_4) and hydrochloric acids (HCl) copper. The inhibitory efficacy of stem and leaf inhibitors rose with rising inhibitor concentrations from 0.2% to 0.8% as well as with decreasing strength of both acids, as shown by both weight loss and thermometric techniques. Maximum inhibitory effectiveness may be found at both the highest inhibitor concentration and the lowest acid concentration (0.5 N). According to the findings of the present study, stem extract is superior than leaf extract in preventing corrosion in H_2SO_4 and HCl acids. The results of thermometric analysis and weight reduction techniques show a strong correlation. Alkaloids, flavonoids, steroids, and tannins, which include more electronegative atoms like O, N, and S with lone pair electrons, as well as π-electron conjugated aromatic rings, are examples of heterocyclic molecules found in the inhibitors, which are responsible for the adsorption process. These atoms combine with the metals vacant d-orbitals to form a coordination link that stops metal ions from dissolving in acidic situations. As a result, metal corrosion is prevented by the presence of inhibitors.

VI. ACKNOWLEDGEMENT

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