ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 4, April 2014

Corrosion Control by Aminoacetic acid (Glycine) an Overview

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Abstract: Glycine has the ability to control corrosion of various metals such as carbon steel, zinc, tin and copper. It behaves as an inhibitor in acid medium, neutral medium and in desecrated carbonated solution. Various techniques like weight loss method, polarization study and AC impedence spectra have been used to evaluate the corrosion inhibition efficiency of glycine. The protective film has been analysed by IR spectroscopy, atomic force microscopy, scanning electron microscopy and auger electron spectroscopy. Adsorption of glycine on metal surface obeys Langmuir, Flory-Huggins or Temkin isotherm, depending on nature of metal and corrosive environment. Polarization study reveals that glycine can function as anodic or cathodic or mixed type of inhibitor depending on nature of metal and corrosive environment.

Keywords: Corrosion inhibition, glycine, amino acids, metals and alloys.

I. INTRODUCTION

Corrosion is the deterioration of metal by chemical attack or reaction with its environment. It is a constant and continuous problem, often difficult to eliminate completely. Prevention would be more practical and achievable than complete elimination. Inhibitors are substance which when added in small quantity to a corrosive environment, lower the corrosion rate. They reduces the corrosion by either acting as a barrier, by forming an adsorbed layer or retarding the cathodic and / or anodic process. Amino acids form a class of non-toxic organic compounds which are completely soluble in aqueous media and produced with high purity at low cost. These properties would justify their use as corrosion inhibitors. The literature presents some studies involving Glycine on the corrosion prevention [8-63].The adsorption of amino acid on carbon steel in acidic environment have been investigated by Akiyama and Nobe [1].Copper dissolution behaviour in EDTA and glycine was first examined by producing potential –pH diagrams for the copper-water-EDTA and Copper-water-glycine systems[2].Many researchers investigated the inhibition effect of environment friendly inhibitors like amino acids on metal corrosion[3,4],which exhibit excellent properties such as good water solubility and rapid biodegradability[5].Various amino acids have been used to inhibit the corrosion of metals and alloys[6,7]Corrosion control of metal is of technical, economical, environmental and aesthetical importance. The use of inhibitor is the best way to prevent metal and alloys from corrosion. Glycine H2N CH2 COOH has two polar groups, namely, one amino group and one carboxyl group. It can coordinate with metals through the nitrogen atom and oxygen atom of the carboxyl group. So it has been widely used as corrosion inhibitor. It has the ability to control the corrosion of a wide variety of metals such pure iron, carbon steel, zinc and tin. It behaves as corrosion inhibitor in acid medium, neutral medium and in deaerated carbonate solution. Various techniques have been used to evaluate the corrosion inhibition efficiency of glycine and to analyse the nature of protective film formed on the metal surface. Depending on the nature of metal and nature of corrosive environment glycine obeys different types of isotherms and behaves as different type of inhibitor, namely anodic, cathodic or mixed type.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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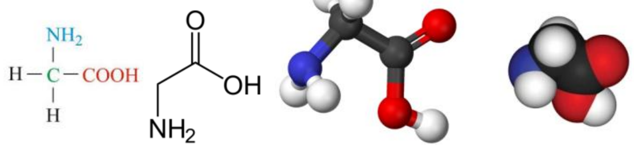
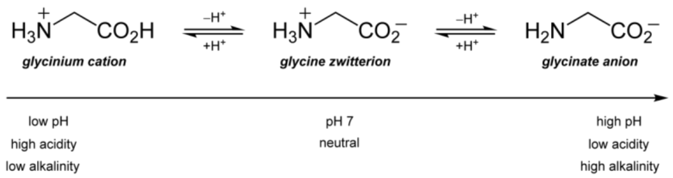
Vol. 3, Issue 4, April 2014

Scheme – 1



Structure of Glycine

Scheme – 2



Structure of Glycine at different pH

1.1. Metals

Glycine and derivatives of glycine have been used to prevent the corrosion of a wide variety of metals. Glycine and its derivatives have the ability to prevent the corrosion of carbon steel (mild steel) [11,15,22,24,25,26,28,32,34,36,37,49,51,52,54,57,58,60,61,63],Cu-Ni alloys [33], Aluminium [14,35,41,48,50], Aluminium 6063 alloy [13], aluminium silicon carbide composite [31,38], pure iron [19,27], steel [20,25,32,42,44,56],tungsten stainless steel [12],316 stainless steel [55], AI SI 304 stainless steel [9], Brass [47], Al-Mn alloy [41], hematite [21], copper [29,30,33,40,43,46,53,56,59,62], zinc [10,20,23,41], tin [16,17,18], vanadium[39], cadmium [8], cobalt [45].

1.2. Environment

Glycine and its derivatives have been used as inhibitor to prevent corrosion of metals in various environments-acidic, neutral and deaerated carbonate solution. The mainly used acid is hydrochloric acid [8,12,22,23,25,28,31,32,36,38,42,44,53,56,58] and rarely rsed acids are sulphuric acid [35,45,46,51,55,57], citric acid [16,27], and acetic acid [10]. It was observed that glycine accelerated the corrosion of electrodeposited cadmium in 1.0m acetic acid [8]. In citric acid, the corrosion of pure iron has been prevented by glycine, leucine, DL-aspartic acid, arginine and methionine [27].In neutral medium the chloride ion is used as corrosive agent[9,24,26,33-35,37,49,52,63]. Synergistic influence of metal ions such as Ca^{2+} and Zn^{2+} on the inhibition efficiency of N-phosphonomethyl glycine, in controlling corrosion of carbon steel in neutral solution has been reported [11]. In deaerated carbonate solution, the corrosion of aluminium 6063 alloy has been prevented by addition of alanine, glycine, serine and methionine [13]. Methionine was adsorbed on the aluminium surface according to a Temkin isotherm model [13]. Corrosion of aluminium in acid-chloride solution has been prevented by amino acids. The acidic amino acids were able to inhibit aluminium corrosion [35].

II. TECHNIQUES

Even though several modern techniques are on the anvil, the mainly used methods in evaluation of inhibition of metals are weight loss method[11,20,22,23,25,27,28,34-36,40,57,60,61], elecrochemical studies such as polarization and AC impedence spectra [9,13,15,18,19,23,17,24,26,27,32,23,39-41,42,44,46,47,50-53] and cyclic voltametry [14,53].

XPS has been used to analysed the film formed on carbon steel surface immersed in neutral chloride solution in presence of N-phosphonomethyl glycine (NPMG)-Zn2+ system. The study revealed that the protective film consisted mainly of hydrous ferric oxides (Fe(OH)3 and FeOOH), with small amounts of Fe-NPMG complex, ZnO and corrosion products [26]. SEM technique has been used to study the morphology of the corroded surface of zinc in HCl medium in the presence of glycine and methionine [23]. Hilden et. Al [19] have used XPS and insitu Atomic Force Microscopy (AFM) technique to study the surface morphology of the film formed on iron/electrolyte interphase in presence of N,N-di(phosphonomethyl) glycine. Section analysis (AFM) revealed the degree of deterioration of the passive layer.

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International Journal of Innovative Research in Science, Engineering and Technology

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Infrared spectroscopy has been used analysed the protective film formed on aluminium 6063 alloy, in deaerated carbonate solution containing amino acids such as glycine and alanine[13]. Shaban et al [26] have investigated the corrosion behaviour of carbon steel in neutral solutions in presence of N-phosphonomethyl glycine. The layers formed on carbon steel were sputtered by an argon beam to obtain a depth profile using Auger Electron Spectroscopy (AES).

2.1. Adsorption isotherms

The protective nature of glycine is attributed to its adsorption on the metal surface. Various adsorption isotherms have been proposed. The adsorption isotherms include Langmuir isotherms [25,28,34,36], Flory-Huggins isotherm [17,32] and Temkinisotherm[13,23,27,31,35,42,51,62].

2.2. Langmuir adsorption isotherm

This type of isotherm is observed when mild steel is immersed in HCl, in the presence of isatin glycine and isatin. First order type of mechanism has been proposed from the kinetic treatment of the result [36]. Similar observation has been made when mild steel was immersed in HCl, in the presence of 2-hydroxy-1-naphthaldehyde glycine and 2- hydroxy-1-napthaldehyde [34], and also when mild steel was immersed in HCl, in presence of anisaldehyde glycine and anisaldehyde [28].

2.3. Flory-Huggins isotherm

This type of isotherm is obeyed when carbon steel is immersed in HCl, in the presence of decylamides of α-amino acid derivatives [32]. Sayyah et al [17] observed that Flory-Huggins isotherm is obeyed when tin was immersed in 1M NaCl in the presence of poly (propenoyl glycine).

2.4. Temkin isotherm

This type of isotherm is obeyed when pure iron is immersed in citric acid in the presence of amino acids such as glycine, leucine, DL-aspartic acid, arginine and methionine [27]. Rajappa and Venkathsha observed Temkin isotherm when zinc was immersed in HCl, in the presence of glycine and methionine [23]. Temkin isotherm was observed when aluminium 6063 alloy was immersed in deaerated carbonate solution in the presence of amino acids such as glycine, alanine, serine and methionine[13].
This type of adsorption very much depends on the nature of metal, environment and amino acids used.

III. MECHANISM OF CORROSION INHIBITION

Glycine H2NCH2COOH, has two polar groups, namely, one amino group and one carboxyl group. It can coordinate with metals through nitrogen atom and oxygen atom. Inhibition of corrosion of metals by glycine is attributed to the adsorption of glycine on the metal surface. The adsorption obeys Langmuir isotherm or Flory-Huggins isotherm or Temkin isotherm depending on the nature of metal and corrosive environment. Adsorption may be physisorption or chemisorption[33]; film formation is also attributed [19]. Hilden et al [19] have detecte the presence of iron-N,N-di(phosphonomethyl) glycine complex. The degree of inhibition efficiency depends on molecular structure of glycine and its solubility rather than difference in molecular weights alone[32,34,36]. Strength of the inhibitor by glycine[34]. Olivares et al [32] while studying the amino acid derivatives suggested that organic molecules were adsorbed and displaced water molecule from the metal surface.Pech-Canul and Echeverria while studying, in the presence of N-phosphonomethyl glycine-Zn2+ system. Observed that the corrosion behaviour of the metal-layer solution system was strongly dependent on the physio chemical properties of the corrosion products-corrosion inhibitor porous layer[26].
Polarization study reveals that glycine functions as anodic inhibitor or cathodic inhibitor or mixed type of inhibitor depending on the nature of environment and nature of metal.

3.1. Anodic inhibitor

Decylamides of tyrosine and glycine function as anodic inhibitor in controlling corrosion of carbon steel in HClmedium[32].

IJIRSET

ISSN: 2319-8753

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3.2. Cathodic inhibitor

Glycine, leucine, DL-aspartic acid, arginine and methionine behaved as cathodic inhibitors in controlling corrosion of pure iron in citric acid [13]. Glycine functioned as cathodic inhibitor in controlling corrosion of tin in three fruit juices, namely, orange, mango and pine apple[10].

3.3. Mixed type inhibitor

N-phophonomethyl glycine-Zn^{2+} system retarded both the anodic and cathodic partial reactions of carbon steel in neutral chloride solutions[24,26]. This view is supported by the study of Chi-Canul [15]. N-acetyl glycine functioned as mixed type inhibitor in controlling corrosion of zinc and steel in an acid sulphate and chloride electroplating bath[19].

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3.4. Corrosion Inhibition by Glycine

S.No	Metal	Medium	Inhibitor	Additive	Method	Findings	Reference
1	Cadmium	1.0M Acetic acid	Chloral hydrate, aniline, P-anisidine and thiodemicarbazide.	Potassium dichromate, glycine, L-leucine, L-Valine		Cathodic current density of cadmium deposition rate of electrolytic cadmium takes place.	8
2	AISI 304 Stainless steel	0.1 N Cl^-	Na p-n-dodecyl benzene sulphonate(DBS), Na dodecylsulphate, Na N-n-dodecanoylsareosine and N-(Carboxymethyl)-N-dodecyl.glycine(LADA)	-	Electrochemical measurements	Pitting potential is 0.7V throughout the pH range	9
3	Zinc	Gelatine, soluble starch and poly vinyl alcohol	Glycine, L-alanine and L-valine	-	Pitting corrosion current measurements	Glycine can be used at low concentration also.	10
4	Carbon Steel	Water	N-Phosphono methyl glycine.	Ca^{2+}, Zn^{2+}	Auger electron spectroscopy and weight loss methods .		11
5	Tungsten Steel	HCl	Methionine, Citrulline, Alanine, Glycine, Hydroxyproline	-	Potentiodynamic polarization and Polarization resistance methods.	Intermetallic compound Fe_3W_2 form galvanic cell with matrix around Fe_3W_2 phase.	12
6	Aluminium	Deaerated	Alanine(ALAOH),	-	IR and Electro	METOH is the best	13

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	6063	carbonated solution	Glycine(GLYOH), Serine(SEROH) and Methionine(METOH).		chemical polarization	inhibitor, it's a mixed type inhibitor and obeys temkin adsorption isotherm	
7	Aluminium	0.1MNaCl	α – Amino acids	-	Potentiodynamic polarization technique and cyclic voltammetry	Argenine is the best inhibitor	14
8	Carbon Steel	Neutral solution	N-Phospho-no-methyl glycine	Zn^{2+}	Electrochemical impedence studies.	Mixed type inhibitor	15
9	Tin	Citric acid	Glycine	Nitrate, Sucrose	Potentiodynamic polarization	Glycine gives 90% inhibition efficiency and citric acid acts as a cathodic inhibitor.	16
10	Tin	1M NaCl	Poly(Propenoyl glycine), Polyacryl amide	-	Potentiodynamic polarization	Obeys Flory-huggins adsorption isotherm	17
11	Tin	3.5% NaCl	Glycine, Serine, Methionine, Vitamin C	-	Potentiodynamicpolarization,Electrochemicalimpedence studies and SEM	Methionine is controlled by charge transfer and diffusion control is dominant.	18
12	Iron	Electrolyte	N,N-di(phosphono methyl glycine)(DPMG)	Ba^{2+},Sr^{2+}, Ca^{2+}, Zn^{2+}	XPS,AFM and electrochemical impedence studies	Bivalent cationssynergitically improve activity of DPMG and Zn2+ influence both anodic and cathodic processes	19
13	Steel&Zinc	Acid sulphate and chloride	N-Acetyl glycine(NAG)	Sodium Larylsulphate(SLS)	Weight loss method and potentiodynamic polarization.	SLS shows the maximum inhibition than NAG and both anodic and cathodic processes are inhibited	20
14	Hematite	$NaClO_4$	Inorganic and organic compounds	-	Indirect radiotracer technique	Displacement of sulphatespecies takes place.	21
15	Mild Steel	2M HCl	Cp-Glutaraldehyde, Glycine and Glutaraldehyde ,methionine	-	Weight loss method and galvanostatic polarization technique	Glutaraldehyde,methionine has better inhibition efficiency than glutaraldehyde glycine.	22
16	Zinc	HCl	Glutaraldehyde, glycine,methionine and Cp of glutaraldehyde,glycine and Cp of glutaraldehyde,methionine.	-	Weight loss method,Electrochemicalimpedence studies and SEM	Cp of glutaraldehyde, methionine is a good inhibitor than glutaraldehyde, glycine, Cp of glutaraldehyde methionine has inhibition efficiency of 92.56% and obeys Temkin adsorption	23
17	Carbon	Neutral	N-Phosphono-	Zn^{2+}	Electrochemical	NPMG/Zn2+inhibits	24

ISSN: 2319-8753

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	Steel	Chloride solution	methyl.glycine(NPMG)		impedence studies	both anodic and cathodic reactions	
18	Steel	HCl	Alanine, Glycine and Leucine	-	Weight loss method and potentiodynamic polarization method	Inhibition efficiency ranges from 28%-91% and it obeys Langmuir adsorption isotherm	25
19	Carbon steel	Neutral chloride solution	N-Phosphono-methyl-glycine(NPMG)	Zn^{2+}	Electrochemical impedence studies, XPS and Auger electron spectra	Inhibition efficiency is upto 85-95% and protective film contains hydrous ferric oxides(Fe(OH)3 and FeOOH), Fe-NPMG complex ,ZnO	26
20	Iron	Citric acid	Glycine, Leucine, DL aspartic acid, Arginine and Methionine	-	Electrochemical impedence studies, potentiodynamic polarization and weight loss methods	Inhibition efficiency is upto 96%,ObeysTemkin adsorption and it's a cathodic inhibitor.	27
21	Mild steel	HCl	Anisaldehyde glycine and anisaldehyde	-	Weight loss method	Inhibition efficiency is 89% for anisaldehyde glycine and 82% for anisaldehyde and both obey Langmuir adsorption isotherm	28
22	Copper	Glycine, H_2O_2	Ammonium dodecyl sulphate(ADS)	-	Electrochemical mechanical planarization method	ADS is superior inhibitor to benzotriazole and its an environmentally safe surfactant.	29
23	Copper	1%glycine and H_2O_2 5%	Ammonium Dodecyl sulphate surfactant	-	Chemical, mechanical planarization (CMP)	ADS,SDS is superior inhibitor to benzotriazole and it suppresses polishing rate of Copper	30
24	Al-SiC	0.01,0.1 and 1 N HCl	Glycyl glycine	-	Polarization techniques	Its an anodic type inhibitor and it obeys temking adsorption isotherm	31
25	Steel	HCl	Dodecylamides of α – Amino acid derivative	-	Electrochemical impedence studies, gravimetric techniques, potentiodynamic polarization and XPS.	Tyrosine and valine have 80% inhibition efficiency, Tyrosine and glycine have 90% inhibition efficiency, they obey Flory-Huggins adsorption isotherm, Tyrosine and glycine are anodic inhibitors ,alanine and valine are cathodic inhibitors	32

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26	Cu-Ni	Neutral chloride	Glycine, Cysteine	-	Electrochemical impedence studies and potentiodynamic polarization.	Glycine have 85% inhibition efficiency at a concentration of 0.1mM, cysteine have inhibition efficiency of 96% at a concentration 2.0mM and physical adsorption takes place on alloy surface	33
27	Mild steel	HCl	2-hydroxy-1-napthaldehyde glycine(HNG) and 2-hydroxy -1-napthaldehyde(HN)	-	Weight loss method	HNG have higher inhibition efficiency than HN and obeys Langmuir adsorption isotherm	34
28	Aluminium	1N HCl and 1N H_2SO_4	Glycine	-	Weight loss method and potentiodynamic polarization.	It obeys temkin adsorption isotherm and it's a mixed type inhibitor.	35
29	Mild Steel	HCl	Isatin and Isatin glycine	-	Weight loss method	Obeys Langmuir adsorption isotherm and inhibition efficiency of isatin glycine is 87% and that of Isatin is 84%.	36
30	Carbon Steel	Low chloride solution	N,N-bis(phosphonomethyl) glycine	Zn^{2+}, Ascorbate	XPS and FTIR	Inhibition efficiency is upto 94% and it's a mixed type inhibitor	37
31	6061 Al-Si(Cp)	HCl	AllylThiorea, glycyl glycine	-	Potentiodynamic polarization	Both of them are anodic inhibitor and moderately inhibits corrosion	38
32	Vanadium	Water	Glycine, Alanine, Valine, Histidine, Glutamic acid and Cystein	-	Potentiodynamic polarization and electrochemical impedence studies	All follow Freundlich adsorption isotherm, glutamic acid and histidine show high inhibition efficiency at low concentration.	39
33	Copper	Nitric acid	Arginine, Lysine and Cysteine	-	Weight loss method and electrochemical impedence studies	Cystien is the best inhibitor and inhibition efficiency is upto 61%	40
34	Carbon steel Zn/Al Galvanised steel Al-Mn	Alkaline solution	POD oils and thiol compounds	Glycine	Scanning vibrating electrode technique,optical and electrochemical impedence studies	POD oils are anodic inhibitors	41
35	ASTM A213 grade T22 boiler steel	0.5 M HCl	Glycine	-	Potentiodynamicpolarization,EIS,SEM, X-ray EDX and Electrochemical	It's a mixed type inhibitor and it obeys temkin adsorption	42

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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					frequency modulation		
36	Copper	Water	Glycine, alanine, methionine,glutamicacid,formic,acetic ,n-butyric,gluraric acid	-	EMF measurements	Amino acids are good inhibitors than aliphatic acids	43
37	Cold rolled steel	1 M HCl	Glycine and 2-bis(2-aminoethyl amino) acetic acid	-	Tafel and linear polarization, EIS, EFM, inductively coupled plasma atomic emission spectroscopy, Quantum chemical method and Density function theory.	They are mixed type inhibitors and by adsorption studies oxide film and NH linkages of inhibitor are found	44
38	Cobalt	Sulphuric acid	Glycine, Alanine, valine, leucine, isoleucine, serine,threonine,methionine,phenylanine, tyrosine, tryptophan, aspartic acid, asparagine glutamic acid and lysine	-	Quantum chemical methods and Density functional method	They exhibit good inhibition efficiency	45
39	Copper	O_2 saturated H_2SO_4	Glycine,alanine, valine, tyrosine	-	Tafel and linear polarization,EIS, EFM, ICP-AES	Alanine and valine have inhibition efficiency of 75%, Tyrosine and glycine show inhibition efficiency of 98% &91% and O_2 reduction at copper electrode is 4 electron process.	46
40	Brass	0.6 M aqueous NaCl	Glycine, L-aspartic acid, L-glutamic acid and their benzenesulphonyl derivatives	-	Potentiodynamic polarization and electrochemical impedence studies	Benzenesulphonyl derivative of glycine is best inhibitor, C_6H_5-SO_2 increases inhibition efficiency due to high molecular size and inhibition efficiency is about 81.2% and 85.5%.	47
41	Aluminium	SCN^- solution	glycine	-	ICP-AES, linear and cyclic polarization, SEM, EDX and open circuit potential is	Due to adsorption of SCN- in glycine decreases the corrosion rate.	48

					monitored		
42	Carbon steel	Low chloride aqueous medium	N,N-bis(phosphor-no-methyl)glycine	Tungstate, Zn^{2+}	Potentiodynamic polarization, XPS, FTIR and SEM	It's a mixed type inhibitor, and surface film has iron oxides/hydroxides, zinc hydroxide, heteropolynuclearcomples [Fe(III), Zn(II)-BPMG]& WO_3	49
43	Aluminium	0.5M KSCN	2(4-dimethylamino) benzylamino) acetic acid hydrochloride glycine	-	Tafel and linear polarization, EIS, SEM, ICP-AES, Cyclic polarization, potentiodynamic polarization and galvanostatic measurement	The glycine derivative has a inhibition efficiency of 97%	50
44	Mild steel	4.0M H_2SO_4	2(4-dimethylamino) benzylamino) acetic acid hydrochloride) glycine derivative1 and glycine derivative 2	-	Linear polarization resistance, EIS and ICP-AES,	Both are mixed type inhibitor and obey temkin adsorption	51
45	Carbon steel	Low chloride solution	N,N-bis(phosphono-methyl) glycine	Phosphonic acid,Zn^{2+}	EIS, Potentiodynamic polarization, XPS, SEM and FTIR	By Deconvolutionpresence of iron(III)oxides/hydroxides, $Zn(OH)_2$ and Zn(II)-BPMG complex and XPS shows the presence of Fe,P,N,C,O and Zn.	52
46	Copper	0.5 HCl	Glutamic acid, glycine and cystiene	-	EIS, Cyclic voltammetry and Parametric method.	Inhibition efficiency of glutathione is 96.4%, inhibition efficiency of cysteine is 92.9% and glutathione has high inhibition efficiency than cysteine	53
47	Carbon steel	Crude oil	Dipeptide benoylalanyl glycine methyl ester and benzoylalanyl glycine	-	IR, MS, NMR spectroscopy and tafel extrapolation	Inhibition efficiencies are 63.34%,35-86%, 68-40% and 27-72%, Results showed formation of dipeptide from carboxylic protected glycine, amine protected alanine and corrosion inhibition increases due to acidity centre in structure of	54

						glycine and L-alanine.	
48	315L Stain less steel	1.0 Sulphuric acid	Glycine,leucine and valine	-	Open circuit potential and potentiodynamic polarization.	Glycine has inhibition efficiency 84.2% and its anodic type inhibitor.	55
49	M3 Copper and Steel	0.5 M HCl	Glycine, threonine, Phenylalanine and glutamic acid	-			56
50	Mild steel	H_2SO_4	Leucine, alanine and glycine	-	Weight loss method, gasometric method and chemical methods.	Physical adsorption takes place and electrophilic attack is at carboxyl functional group and inhibitors.	57
51	Mild steel	0.1 N HCl	Cystein, glycine, leucine, and alanine	-	Quantum chemical, gravimetric,gasometric, thermometric methods, FTIR, QSAR and DFT.	Cystein has high inhibition efficiency and physisorption takes place	58
52	Copper	Nitric acid	Arginine, Cysteine, Glycine, Lysine, Valine.	-	Austine model	Cystein is the best inhibitor out of all and the functional groups are (NH3+HS,COOH)	59
53	Carbon steel	Well water	Glycine	Zn^{2+}	Weight loss method and potentiodynamic polarization.	Inhibition efficiency is upto 86% and its mixed type inhibitor.	60
54	Mild steel	Well water	Glycine	Zn^{2+}	Weight loss method and potentiodynamic polarization	Inhibition efficiency is 86% and it's a mixed type inhibitor.	61
55	Copper	8M phosphoric acid	Proline, cysteine, phenyl alanine, alanine, histidine, glycine.	-	Potentiodynamicpolarizationand Quantum chemical methods	They follow Tempkin adsorption, amino acids are good inhibitors and physical adsorption takes place.	62
56	Carbon steel	Low chloride neutral aqueous medium	N,N-bis(phosphono methyl) glycine(BPMG)	Zn^{2+}, citrate ion	Potentiodynamic polarization, EIS, XPS and SEM	Mixed type inhibitor and deconvolution spectra shows presence of oxides/hydroxides of [Iron(III), Zn(II)-BPMG-citrate] Heteropolynuclearmulti ligand complex	63

IV. ACKNOWLEDGEMENT

The authors are thankful to their managements and University Grants Commission, India, for their help and support.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 4, April 2014

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ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 4, April 2014