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A Review on the Assessment of Amino Acids Used As Corrosion Inhibitor of Metals and Alloys

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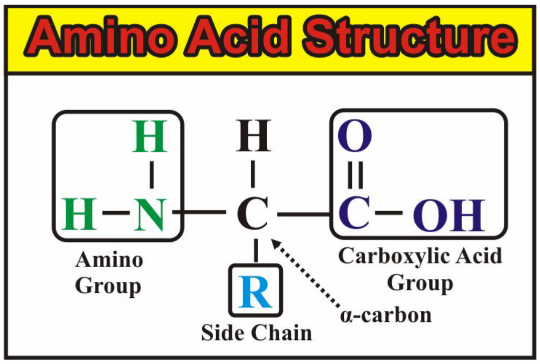
Abstract: Corrosion control of metals is an important activity of technical, economic, environmental, and aesthetical importance. The use of inhibitors is one of the best options of protecting metals and alloys against corrosion. The toxicity of organic and inorganic corrosion inhibitors to the environment has prompted the search for safer corrosion inhibitors such as green corrosion inhibitors as other more environmental friendly corrosion inhibitors, most of which are biodegradable and do not contain heavy metals or other toxic compounds. Amino acids have 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 deaerated carbonated solution. Various techniques like weight loss method, polarization study and AC impedance spectra have been used to evaluate the corrosion inhibition efficiency of amino acids. The protective film has been analysed by IR spectroscopy, atomic force microscopy, scanning electron microscopy and auger electron spectroscopy. Adsorption of amino acids on metal surface obeys Langmuir, Flory-Huggins or Temkin isotherm, depending on nature of metal and corrosive environment. Polarization study reveals that Amino acids can function as anodic or cathodic or mixed type of inhibitor depending on nature of metal and corrosive environment. The article enumerates several kinds of Amino acids which are suitable for

use in combating corrosion, and several which have suitable strength characteristics as to serve in place of scarce expensive metals and alloys.

Keywords: Amino Acids, Metals and Alloys, Acid, Alkaline, Corrosion inhibitor

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. 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. Inhibitors are substance which when added in small quantity to a corrosive environment, lower the corrosion rate. They reduce the corrosion by either acting as a barrier, by forming an adsorbed layer or retarding the cathodic and / or anodic process. Several researches have indicated that Amino acids can be used as corrosion inhibitors because, through their functional groups, they form complexes with metal ions and on metal surfaces. These complexes occupy a large surface area, thereby blanketing the surface and protecting the metals from corrosive agents present in the solution. 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. 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 amino acids and to analyse the nature of protective film formed on the metal surface. Depending on the nature of metal and nature of corrosive environment amino acids obeys different types of isotherms and behaves as different type of inhibitor, namely anodic, cathodic or mixed type. The literature presents some studies involving amino acids on the corrosion prevention[1-148].



Disscusion:

Metals and Alloys: Amino acids and derivatives of amino acids have been used to prevent the corrosion of a wide variety of metals. Amino acids and its derivatives have the ability to prevent the corrosion of

Carbon steel (Mild steel)[1,2,5-8,10,12 ,14-16 ,28-31,37,41,46,52,55,58,59,64,71, 72,75-77,84,86,88-90,92,97,98,101,107,109,112,115,116,128,140, 141,143,145],Copper[3,4,9,11,21,23,24,26,32,34,43,44,48,54,60,62,66,69,73,78,80,83,87,99,119,120,129,138],Aluminium[36,38,47,70, 91,94,100,102,104, 114,131,134],Iron[19,33,61,65,74,106,117,123,136,144],Vanadium[67],Pb[79],Zn[95,113,122,135],Tin[108,110,111,124,125,127],Cobalt[142], Cadmium[147],Brass[20,22,39,118],Bronze[17,53,57],Steel[40,49,51,56,105,122,126,130,137,139,146,148],Cu-Ni alloys[42,103],Aluminum and Zinc pigments[121] ,Stainless steel[13,133],Chromium alloy steel[27,50,63],Mg-Al-Zn alloy[18],Cu-Ni alloy[42,103],Pb-Ca-Sn alloy[68],Ca-Ni alloy[93],Pb-Sb-Se-As alloy[96] Al alloy[45,132],Reinforcing steel[25].

Environments: Amino acids and its derivates have been used as inhibitor to prevent corrosion of metals in various environments - acidic, alkaline, neutral and deaerated carbonate solutions, etc. The mainly used acids are hydrochloric acid[3,6,11,14,16,23,31,33,40,41,43,46,48,49,52,56,58,60-64,70,73,77,78,80,83,87,89-92,94,95,97-101,104,105,109,113,115, 129,133,136,138,141,144]and Sulphuric acid[6,13,15,24,30,34,35,42,59,65,68,74-76,84-86,91,96,100,109,119,126,130,142,143,145].Rarely used acids are Nitric acid[4,26,44,69,118,148], Citric acid[106,108,127], Acetic acid[147], Sulfamic acid[27,50,72], Phosphoric acid[116],Acidic sulfate solution[103,122],Acidic Chloride solution[134],Acidic sulphate and chloride solution[122], Acidified $CuSO_4$[21],$HCl+CaCl_2+NaCl$[45].In neutral medium the chloride ion is used as corrosive agent[10,18,20,37,39,47,71,83,93,95,107,112,120,124,125,131]and other environments are Deaerated carbonate solution[132], $NaHCO_3+Na_2SO_4$ aqueous solution[17,53,57],KSCN[36,38],Neutral aqueous solution[140], NaOH[22,102, 114,121,146],Different pH[67,79,137,139],Water in oil field[81,82],Refined test water[19],Synthetic produced water[51],Well water[1,2,5,7,8],Rain water[28],Articificial seawater[32],Citric chloride solution[110,117],Fruit juices[111], Lime fluid[88],Cassava fluid[55]

Synergistic effect: The enhancement of the inhibition efficiency caused by the addition of metal ions or other inhibitors to Amino acids is due to the synergistic effect. Synergistic influence of metal ions such as Zn^{2+} ion [1,2,5,7,8,10,28,37,60,71,107,112,123,125],iodideion[48,62,74,76,80,85,86],Tungstate ion[37], Ba^{2+}[123],Sr^{2+}[123],Ca^{2+}[123] and other additives are Phosphonic acid[10],Cysteine[20], CTAB&CPB[23], SG[28], BTAH&ADS[66],Ascorbate[71],1-Dodecanoic acid[73],HEDP[81,82],Calcium oxide[102].

Techniques: Even though several modern techniques are on the anvil, the mainly used methods in evaluation of inhibition efficiency of amino acids in preventing corrosion of metals and alloys are weight loss method[1,2,5,7,8,15,16,31,44,46,55,63,64,68,69,77,88,90,91,92,96-101,104,406,109,113-115,119,122,136,140], electrochemical studies such as polarization and AC impedance spectra[1-3,5-8,10-13,17,18,22-25,27,28,30,31,33,34,36,37,39-46,48-50,53,56,58-63,66-70,72-80,83-87,89,91,93-100,102-108,110,112-118,120,122-129,132-134,136,142,145-147] and cyclic voltammetry[11,23,131]. XPS has been used to analyze the film formed on the metal surface[10, 37,49,71,89,107,123]. SEM technique has been used to study the morphology of the surface film in the absence and presence of Amino acids[1,2,5,7,8,10,16,28,37,51,61,71,78,132].FTIR spectra have been used to analyze the protective film formed on the metal surface[1,2,5,7,10,17,22,37,38,45,51,56,63,65,68,100,113,124,140].The EDAX spectra were used to determine the elements present on the metal surface before and after exposure to the Amino acids solution[1,2,5,38,56,63]. Atomic force microscopy (AFM) is a powerful technique for gathering roughness statistics from a variety of metal surfaces[7,8,76,86,123]. The quantum chemical study[15,26,29,35,40,41,48,52,61,62,65,69,78]and molecular dynamics simulation[9,46,65]were applied to find the equilibrium adsorption configuration and calculate the interaction energy between Amino acids and metal surface.DFT has been used to study the structural properties of Amino acids in aqueous phase in an attempt to understand their inhibition mechanism[33,40,46].

Adsorption isotherms: The protective nature of amino acids have attributed to its adsorption on the metal surface. Various adsorption isotherms have been proposed. The adsorption isotherms include Langmuir isotherms[6,16,18,46,56,60,61,68,72,79,80,83,86,90,92,95,96,100-102,105,116,126,141], Flory- Huggins isotherm[89, 125, 134], Freundlich isotherm[18,67],Temkin isotherm[30,32,49,56,63, 72,84,91,94,97,98,106], [109,113,117,132],Frumkin isotherm[100, 110, 118, 136],Bockris – Swinkels'isotherm[119].An adsorption isotherm very much depends on the nature of metal, environment and Amino acids used.

Mechanism of Corrosion inhibition by Amino acids: Amino acids have 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 amino acids is attributed to the adsorption of amino acids on the metal surface. The adsorption obeys Langmuir isotherm or Flory- Huggins isotherm or Temkin isotherm or Freundlich isotherm or Frumkin isotherm or Bockris – Swinkels' isotherm depending on the nature of metal and corrosive environment. Adsorption may be physisorption or chemisorption[18], [93] ; film formation is also attributed [44,52, 88,100]. The degree of inhibition efficiency depends on molecular structure of amino acids and its solubility rather than difference in molecular weights alone [29,33,39]. Strength of the inhibitor-metal bond also plays a major role in deciding the degree of inhibition by amino acids [35]. Polarization study reveals that amino acids functions as anodic inhibitor[1,2,5,7,8,70,84,89,94,98,146] or cathodic inhibitor[22,33,43,45,46,49,73,74,87,89,97,98,110,118]or mixed type of inhibitor[10,24,33,37,40,56,58,59,63,74,77,86,91,107,112,114,117, 123, 128,134,145,146]depending on the nature of environment and nature of metal.

CONCLUSIONS

It has been shown that Amino acids are efficient corrosion inhibitors in different aqueous media. Mechanism of inhibition are mainly attributed to adsorption and depends on the metal, physicochemical properties of the molecule such as functional groups, and p orbital character of donating electrons, as well as the electronic structure of the molecules. In other words, the efficiency of Amino acids as corrosion inhibitor depends not only on the characteristics of the environment in which it acts, the nature of the metal surface, and electrochemical potential at the interface, but also on the structure of the inhibitor itself, which includes the number of adsorption active centers in the molecule, their charge density, the molecular size, the mode of adsorption, the formation of metallic complexes, and the projected area of the inhibitor on the metallic surface. The results of the series of investigations have revealed that the processes involved in corrosion inhibition are not uniform with respect to all classes of compounds so far investigated and are not even constant or consistent with one inhibitor in a given system. Indeed, the overall process is a function of the metal, corrodent, inhibitor structure, and concentration, as well as temperature.

Table: Corrosion inhibition by Amino Acids

S. No.	Metal	Medium	Additive	Inhibitors	Method	Findings	References

1	Carbon Steel	Well water	Zn^{2+}	L- Cysteine	Weight loss, Electro-chemical study, FT-IR, UV visible, SEM, EDAX	L- Cysteine and Zn^{2+} offers good inhibition efficiency of 97%.	**1**
2	Carbon Steel	Well water	Zn^{2+}	L-Histidine	Weight loss, Electro-chemical study, FTIR, SEM,EDAX	L-Histidine acts as a good inhibitor at pH 7.8 and protective film consists of Fe^{2+} - L-Histidine complex and Zn(OH)2	**2**
3	Copper	0.5 M HCl	--	Cysteine and Alanine	electrochemical methods combined with quantum chemical calculations and molecular dynamics simulations	The thiol functional group is responsible for the superior inhibition efficiency of cysteine	**3**
4	Copper	1 M HNO_3	--	Aspartic Acid, Glutamic Acid, Alanine, Asparagine, Glutamine, Leucine , [illegible]	quantum chemical calculations using semi empirical (AM1 and MNDO) and ab-initio methods	Met is the best inhibitor for the corrosion of copper in 1M HNO_3	**4**
5	Carbon Steel	Well water	Zn^{2+}	DL-phenylalanine	Weight loss, Electro-chemical study, FT-IR, UV visible, SEM, EDAX	DL-phenylalanine and Zn^{2+} offers good inhibition efficiency of 90%	**5**
6	Mild steel	1M HCl and 0.5M H_2SO_4	--	L-Cysteine	Electrochemical impedance spectroscopy (EIS) and Molecular dynamics (MD) simulation	Inhibition efficiency increase with the increase of Cys concentration in both acids and obeys Langmuir adsorption isotherm in both acids	**6**
7	Carbon Steel	Well water	Zn^{2+}	DL-arginine	weight-loss method, Polarization study, AC impedance spectra, FTIR, SEM,AFM	The formulation consisting of arginine and Zn^{2+} offers good inhibition efficiency of 98 %	**7**

8	Carbon Steel	Well water	Zinc ion	Glycine	weight-loss method, Polarization study, AC impedance spectra, FTIR, ,AFM	The formulation consisting of glycine and Zn^{2+} offers good inhibition efficiency of 82%.	**8**
9	Cu	--	--	Aspartic acid, Glutamic acid	Molecular dynamics simulation	Inhibition performance of Glutamic acid is better than aspartic acid	9
10	Carbon Steel	Low chloride	Phosphonic acid, Zn ions	BPMG	Potentiodynamic polarization, XPS, FTIR,SEM	Acted as a Mixed type inhibitor	10
11	Copper	HCl	--	Cysteine, Glycine Glutamic acid glutathione	Electrochemical impedance spectroscopy, cyclic voltammetry	Corrosion int he increasing order glutathione> cysteine> cys+glu+gly> glutamicacid> glycine	11
12	CarbonSteel	--	--	Glycine methyl ester, benzoyl alanine, dipeptide benzoyl alanyl glycine, methyester, dipeptide	Tafel method	Dipeptide benzoyl alanyl glycine methylester 68.40%IE	12
13	316LSS	H_2SO_4	--	Glycine, Leucine valine and arginine	OCP, potentio dynamic polarization	Glycine has highest inhibition efficiency82.4%	13
14	Low carbon steel& copper	HCl	--	Glycine, threonine, phenylalanine, glutamic acid	--	Inhibition of corrosion evaluated	14
15	Mild steel	H2SO4	--	Leucine,alanin e and glycine	QSAR, weight loss, gasometric methods and quantum chemical studies	These inhibitors support the mechanism of physical adsorption	15

16	Mild steel	HCl	--	Cysteine, glycine, leucine and alanine	gravimetric, gasometric, thermometric, FTIR and QSAR	IE decreased in the order Cys>leu>ala>glycine	16
17	Bronze	Na2SO4+ NaHCO3	--	Cystein, alanine and phenylalanine	SEM, EIS	IE decreased in the order Cys>ala>Phe	17
18	Mg-Al-Zn alloy	Chloride free neutral solution	--	Amino acids	Polarization techniques &EIS	Phenylalanine has highIE93%	18
19	Iron	refined testing water	--	PASP/ABSA graft copolymer	--	Copolymer inhibit $CaCO_3$and $Ca_3(PO4)_2$scales and had good corrosion inhibition ability	19
20	Brass	NaCl	Cysteine	RmH, RbH	--	In the presence of cysteine, IE of RmH is increased	20
21	Copper	Acidified $CuSO_4$	--	Cystine,Valine, alanine, phenyl alanine, serine and threostine	--	Rate of mass transfer depending on the types of additives and its Concentration	21
22	Brass	O_2 Free NaOH	--	Methionine	polarization, EIS,SEM	MET is a Cathodic inhibitor	22
23	Copper	HCl	CTAB, CPB	Methionine	EIS, cyclic voltammetry	CTAB/MET has better synergistic effect	23
24	Copper	H_2SO_4	--	Cysteine	EIS, polarization &PS study	Act as mixed type inhibitors	24

25	Reinforced concrete	--	--	2amines,4amino acids,3 carboxylates	Polarization study	These inhibitors are the best to preventing chloride induced corrosion	25
26	Copper	Nitric acid	--	Arginine, cysteine, glycine, lysine,	Quantum chemical studies	Cys is the best inhibitor	26
27	Low chromium steelT22	Sulfamic acid	--	Serine	EIS,EFM and LPR	inhibition efficiency increased with increasing inhibitor concentration but decreased with increasing the solution temperature	27
28	Carbon steel	rainwater	Zn^{2+} & SG	L-valine	AC impedance spectra, polarization, FTIR	LV + Zn^{2+} + SG system has98% of IE	28
29	Mild steel	--	--	Skeleton- I, CYS,SER,ABU , Skeleton-II, THR,ALA,VA L, Skeleton-III, PHE,TRP,TYR	Quantum chemical study	Highest inhibition efficiency were obtained for inhibitors in Skeleton-III	29
30	Mild steel	H_2SO_4	--	Glycine,GlyD 1, GlyD2	Polarization and impedance methods	Inhibition performance GlyD1wasmuch better than those ofGlyD2andGly	30
31	Mild steel	HCl	--	CYS,NACY S, NASBCYS, NASHCYS	weight loss & polarization study	IE of the four inhibitors followed the order NASBCYS>NAS HCYS>NACYS> CYS	31

32	Copper	Artificial Sea water	--	Alanine, asparagine, aspartic acid, glutamine, methionine	Explained by Temkin logarithmic isotherm	IE depended on the concentration of amino acids	32
33	Iron	HCl	--	alanine, cysteine, S-methylcysteine	polarization, impedance, EFM, ICP-AES and DFT	Ala-cathodic inhibitor sys & S-MCys mixed type inhibitor	33
34	Copper	H2SO4	--	Glycine, alanine, valine, tyrosine	Polarization, impedance &EFM	IEofTyr-98%, Gly-91%,onthe other hand IE of Ala& Val -75%	34
35	Cobalt	H2SO4	--	Gly, Ala, Val, Leu, Ile, Ser, Thr, Met, Phe, Tyr, Try, Asp, Asn, Glu andLys	Quantum chemical studies	It is found that the calculated results satisfactorily support the experimental findings	35
36	Al	KSCN	--	Gly, GlyD	polarization, Impedance, ICP-AES,SEM	GlyD was much better than Gly in controlling uniform and pitting corrosion processes of Al	36
37	Carbon steel	Low chloride aqueous medium	Tungstate and Zinc ions	BPMG	Polarization, XPS,FTIR,SEM	These formulation function as a mixed type inhibitor	37

38	Al	SCN^- solutions	--	Glycine	ICP-AES,OCP,SEM,EDX	Gly in aggressive SCN^-solutions decreased the corrosion and passive currents and shifted the pitting potential to more noble values.	38
39	Brass	NaCl	--	Glycine(I), L- Aspartic acid(II), L- Glutamicacid (III) and their corresponding benzene sulphonyl derivatives IV, V,VI	Polarization &impedance spectroscopy	Compound VI is the best inhibitor which reaches 81.2 - 85.5%of IE	39
40	Cold rolled steel	HCl	--	Gly & GlyD	polarization, impedance, EFM, ICP-AES, Quantum chemical method and DFT	Gly and GlyD are very good "green" mixed type inhibitors	40
41	Mild steel	HCl	--	L-Cysteine,L-Histidine,L-Tryptophan,L-Serine	polarization, impedance and quantum chemical study	IEof these inhibitors follows the sequence L-Tryptophan>L-histidine>L-Cysteine>L-Serine	41
42	Cu-30Ni alloy	H2SO4	--	Cysteine	Polarization and EIS	IE reaches a value91%	42
43	Copper	HCl	--	Cysteine with DAC and with DAM	Polarization and EIS	Prepared SAM suppress cathodic current densities and sift the corrosion potential toward more negative value.	43

44	Copper	Nitric acid	--	MIT, MITO,MITO2	weight loss, polarization, impedance techniques and fukui functions	Explained inhibition performance and simulate adsorption	44
45	AA2024 aluminium alloys	HCl + $CaCl_2$+ NaCl	--	Tryptophan	Polarization, impedance & SEM	Tryptophan acted as cathodic inhibitor	45
46	Low carbon steel	HCl	--	L-Tryptophan	Weight loss, polarization, DFT and molecular dynamics simulation method	L-Tryptophan act more as cathodic than anodic inhibitor	46
47	Al 7075 rotating disc electrode	NaCl	--	L-glutamine	--	The IE depends on rotation speed	47
48	Copper	HCl	KI	Histidine	Polarization, impedance and quantum chemical methods	Film formed on the electrode is more stable at pH=10than that at other pH values	48
49	ASTM A213 gradeT22boilersteel	HCl	--	Serine	Tafel extrapolation, EFM and XPS examinations	Serine acted mainly as a cathodic type inhibitor	49
50	ASTM A213 gradeT2 (0.5Cr-0.5Mo	Sulfamic acid	--	Serine	EIS&EFM	IE increases with increasing inhibitor concentration, but decreases with	50
51	Steel	Synthetic produced water	--	PGLU	FTIR,XRD,SEM	It prevents corrosion through passivation of steel surface through chelating mechanism	51

52	Mild steel	HCl	--	asparagine, aspartic acid, glutamine,glutamic acid	quantum chemical study	IE of the compound is in the order glutamine>asparagine>asparticacid >glutamicacid	52
53	Bronze	$NaHCO_3$+ Na_2SO_4 aqueous solution	--	DL-alanine, DL- Cysteine	Polarization & impedance spectroscopy	Cysteine reaches 90% of IE	53
54	Copper	--	--	Amino acids and Aliphatic carboxylic acids	EMF measurements	Amino acids act as better corrosion inhibitors than aliphatic carboxylic acids	54
55	NST-44 carbon steel	Cassava fluid	--	Leucine, alanine, methionine, glutamic acid	Weightloss & optical microscopic techniques	Alanine showed highest IE glutamicacid had the lowest IE, leucine, methionine showed considerable	55
56	Low alloy steel (ASTM A213 gradeT22 boiler	HCl	--	Glycine	Polarization, impedance, SEM,EDX, ICP and EFM	Gly is a good "Green "mixed type inhibitor	56
57	Bronze	Na_2SO_4+ $NaHCO_3$ aqueous acidic solutions	--	Glu, Arg, His,Met, Cys	OCP & EIS	IE of the compounds decrease in the order Cys>Glu>Met> Arg>His	57
58	Carbon steel	HCl	--	dodecyl cysteine hydrochloride surfactant with the gold nano particles	polarization, impedance and TEM	Selected additives act as a mixed type inhibitors	58

59	Mild steel	H_2SO_4	---	1-methionine,1-methionine sulphoxide,1-methionine sulphone	Montecarlo simulations technique	Methionie derivatives act as mixed type inhibitor	59
60	Copper	HCl	Zn^{2+}	Methionine	Polarization and EIS	The presence of Zn^{2+}increases the IE to 92%	60
61	Iron	HCl	--	Methionie and Tyrosine	Quantum chemical study, polarization measuresand FTIR	methioninehas highest IEof97.8%	61
62	Copper	HCl	Iodide ion	Arginine	Polarization, EIS and quantum chemical study	Arg+ Iodide ion solution improved the SAM significantly	62
63	Low chromium alloy steel	HCl	--	Tyrosine	EFM, weigh tloss, polarization, impedance, EDAX and SEM	Tyr acted as a mixed type inhibitor	63
64	Carbon steel	HCl	--	Amino acid Schiff bases	weight loss	These inhibitors has very high IE rangedbetween99.93 and 97.98%	64
65	Iron	H2SO4	--	L-Glutamine	EIS, Quantum chemical, SEM and Molecular simulation study	L-Glutamine form films on the surface of iron	65
66	Copper	--	BTAH, ADS	ß- Alanine	ECMP, LSC,FT-EIS	Investigated both individual and combined effects of BTAH and ADS on Cu electro dissolution in the absence of abrasion	66

67	Vanadium	different pH	--	Glycine,alanine, valine,histidine, glutamic acid and cysteine	OCP polarization andEIS	In neutral and basic solutions the presence of AA increases the corrosion resistance of the metal	67
68	Pb-Ca-Sn alloy	H_2SO_4	--	Cys, Met and Ala	Weight loss, Polarization, EIS,SEM	IE of Cys is greater than96%	68
69	Copper	Nitricacid	--	Val, Gly,Arg,Lys, Cys	Weight loss, Polarizationand Quantum chemicalstudy	Gly,Val- accelerate the corrosion process Arg, Lys,Cys- inhibit the corrosion phenomenon	69
70	T-6 treated6 061Al-SlC(p)	HCl	--	Allyl thiourea, GlycylGlycine	Tafel extrapolation technique	Both theo rganic compounds act as anodic inhibitors	70
71	Carbon steel	Low chloride	Zn^{2+}, ascorbate	BPMG	XPS, FTIR	BPMG+ Zn^{2+}+ ascorbate system affored an IE of 94%	71
72	Mild steel	Sulfamic acid	--	S- containing amino acids ACC, RSH, BZC, RSSR and CH_3SR	Polarization, EIS	IE follow the order ACC>RSH>BZC >RSSR≅CH_3SR	72

73	Copper	HCl	1-dodecanoic acid	DL-Cysteine	Electrochemical measurement	Bi layer membrane was assembled ,it strengthen the inhibition for cathodic process of copper electrode and improve the protection effect for copper	73
74	Ingotiron (i)BNII, (ii) CPII,	H_2SO_4	Iodide ions	Cysteine	Polarization and EIS	For CPII, Cys inhibited cathodic reaction, For BNII, Cys inhibited both cathodic and anodic reactions, Iodide ions improved the inhibitive effect of Cys	74
75	Mild steel rotating disc electrode	H_2SO_4	--	1-Methionine	OCP, Polarization and EIS	Low speed rotations did not have notice able changes of IE Higher rotation speeds increased efficiencies	75
76	Low carbon steel, LCS, PC(LCS)	H2SO4	KI	Methionine	Polarization, impedance,X-Ray diffraction andAFM	Methionine inhibited the corrosion of both specimens with comparable IEs, Iodideions synergistically increased the IE	76

77	Mild steel	HCl	--	α-aminoacids alkylamides	Weight loss, polarization and microtox testing	Compounds act as mixed corrosion inhibitors with an efficiency80-90%	77
78	Copper	HCl	--	Three amino acids- serine, threonine, glutamicacid	electrochemical method, FTIR and quantum chemicalstudy	Glutamicacid has improved IE	78
79	Pb	aqueous solution with different pH	--	Different amino acids	Polarization and impedance techniques	IE upto 87%wasrecorded with glutamic acid in neutral solutions	79
80	Copper	HCl	KI	Asp, Glu,Asn,Gln	Polarization, EIS	IE of these compounds increases in the order Gln>Asn>Glu> Asp,Gln+KI system reaching	80
81	--	water treatment in oil field	HEDP, ClO_2, MIT	PAG	Anti scale method	PAG is excellent scale inhibition and good and compatibility with corrosion inhibitor and disinfectant	81
82	--	Water treatment in oil field	HEDP,ClO_2	PAG	Anti scale method	PAG has excellent scale inhibition and is highly compatible with corrosion inhibitor (HEDP) and the disinfectant	82
83	Copper	NaCl and HCl	--	Cysteine	Polarization and EIS	IE 84% could be achieved in chloride solution	83

84	Mild steel	Sulfide-polluted H_2SO_4	--	RSH, RSSR	Polarization and AC impedance technique	RSH & RSSR act as anodic type inhibitors	84
85	Low carbon steel SNCLCS and BLCS	H_2SO_4	KI	Methionine	Polarization & EIS	Methionine inhibited the corrosion of both specimens with comparable IEs and iodide ions synergistically increased the IE	85
86	Mild steel	H_2SO_4	KI	Methionine	Electrochemical techniques and AFM	Compound functioned via a mixed inhibition mechanism	86
87	Copper	HCl	--	BTA, octanoyl glutamic acid, DL- Threonine, DL- serine	Polarization and EIS	These inhibitors suppressed cathodic corrosion reaction of copper, and the best corrosion inhibitor was octanoyl glutamic acid	87
88	NST-44, mild steel	Lime fluid	--	leucine,alanine, methionine and glutamic acid	weight loss	Alanineshowed highest IE	88
89	Carbon steel	HCl	--	decylamides ofα-aminoacids derivatives	gravimetric, polarizationand XPS	Gly and Tyr derivatives acted as anodic inhibitors, Ala and Val derivatives acted as cathodic type	89
90	Mild steel	HCl	--	ING,IN	Weight loss	ING has 87%ofIE	90
91	Aluminum	HCl and H_2SO_4	--	Glycine	Weight loss and polarization method	Glycine is a mixed type inhibitor	91

92	Mild steel	HCl	--	HNG andHN	Weight loss	HNG exhibits higher IE than HN	92
93	Ca-Ni alloys	Neutral chloride solutions	--	Glycine, cysteine	Polarization and impedance techniques	IE of glycine is 85%,Cysteine shows are markable high IE 96%	93
94	Al-Sic(p)	HCl	--	GG	Polarization technique	GG act as an anodic inhibitor	94
95	Zn	HCl and NaCl	--	Onion juice, [S-(1-propenyl)-L-Cysteine sulfoxide which is present in the juice]	Polarization technique	Onion juice reduced the corrosion rate of zinc in the acid solution. In NaClsolution shifts the pitting potential toward more positive direction	95
96	Pb-Sb-Se-As alloy	H_2SO_4	--	Tryptophane, proline, methionine	Polarization and Weight loss methods	Theseinhibitors act as good inhibitors for the corrosion of lead alloy in H_2SO_4 solution	96
97	Mild steel	HCl	--	Tryptophane	Weight loss, polarization and EIS studies	Corrosion is predominantly under cathodic control	97
98	Mild steel	HCl	--	Leucine	Weight loss, polarization and EIS	Corrosion is predominantly under cathodic control	98
99	Copper	HCl	--	DL-alanine, DL-Cysteine	Weight loss and polarization studies	DL-alanine and DL-cysteine acted as an anodic inhibitor	99

100	Aluminium	HCl+ H_2SO_4	--	Alanine,Leucine, Valine,Proline, Methionine and Tryptophan	Weight loss, Polarization and SEM techniques	These amino acids act as good inhibitors for the corrosion of aluminium	100
101	Mild steel	HCl	--	ANG and AN	Weight loss technique	The IEs of 89% and82%have beenobtainedat33 3K for ANG and AN respectively	101
102	Aluminium	NaOH	Calcium oxide	Arginine	Polarization study	Arg alone reaches 50.09% of IE, Arg+ Calcium oxide has maximum IE of 60.65%	102
103	Cu-Ni	Acidic Sulfate solutions	--	Different amino acids	Electrochemical techniques	Some amino acids like lysine have promising corrosion IE at low	103
104	Aluminium	HCl	--	Indigo dye, ß -alanine	Weight loss, OCP and Polarization method	Indigo dye was found to be a better inhibitor	104
105	Steel	HCl	--	Alanine, Glycine and Leucine	Polarization method	The inhibition efficiency IE depended on the type of AA and its concentrations	105
106	Pure Iron	Citric acid	--	Glycine, Leucine, DL-aspartic, arginine and methionine	Weight loss, polarization, EIS measurements	Methionine is the best inhibitor and its efficiency reaches 96%	106
107	Carbon steel rotating disk electrode (RDE)	Neutral Chloride solutions	Zn^{2+}	NPMG	Polarization, XPS and AES	NPMG/Zn^{2+} mixture retarded both anodic and cathodic reactions	107

108	Tin	Citric acid	--	Arginine mono hydrochloride, lysine monohydro chloride, cysteine and methionine	Polarization technique	Nitrogen containing AA gave IE>70% and sulphur containing AA gave IE of 69%and56%	108
109	Mild steel	HCl and H_2SO_4	--	Methionine	Gravimetric technique	IE of methionine depends on the nature of the acid and the concentration of the inhibitor	109
110	Tin	Citric Chloride solution	--	Some amino acids	Polarization technique and using potential current curves	Arginine is the best inhibitor and act as a cathodic inhibitor	110
111	Tin	Fruit Juices	--	Six amino acids	Potentiodynamic method	All the amino acids showed > 94%	111
112	Carbon steel rotating disc electrode	Neutral Chloride solution	Zn^{2+}	NPMG	Electrochemical impedance measurement	NPMG/Zn^{2+} mixtures retarded both anodic and cathodic reactions	112
113	Zin	HCl	--	GTD, GLN, MTN,GTD+ GLN(CP1) and GTD+ Mtn (CP2)	Electrochemical method, Weight loss and SEM	CP2is best inhibitor and that is IE reaches92.56%	113

114	Aluminium	NaOH	--	Lysine	Weight loss, Polarization, gasometric, OCP	Lysine predominantly under anodic control, The nature of the inhibition was found to be of mixed type	114
115	Mild steel	HCl	--	CP1, CP2	Weight lossa nd polarization study	CP2 shows better inhibition than CP1	115
116	Mild steel	Phosphoric acid solutions polluted with Cl^-,F^-	--	Cysteine, ACC, methionine, Cystine	Polarization, EIS	Cysteineand ACCshowed higher IEthan methionineand Cystine	116
117	Iron	Citric-Chloride solution	--	$MetOC_2H_5$	Polarization study	MetOC2H5isa mixedtype inhibitor	117
118	Brass (Cu60-Zn40)	HNO_3	--	Boc-Phe	Polarization study	Boc-Pheactedas cathodicinhibitor	118
119	Copper	H_2SO_4	--	Tryptophan	Potentiodynamic spectro photometric and gravimetric	Tryptophan has 80% of IE	119
120	Copper	NaCl and NaBr solutions	--	V-o-Ph-V,V-p-Ph-VAND V-HS	EIS, polarization techniques	IE of V-o-Ph-V on copper corrosion was highest, V-P- Ph-V the next and V-His the lowest	120

121	Aluminium and Zinc pigments	aqueous alkaline media	--	Different amino and poly amino acids	--	Aspartic acid inhibits corrosion reactions of aluminium pigment only at pH8(IE96%) whereas poly aspartic acid inhibits corrosion reactions of zinc pigment	121
122	Zinc and Steel	acid sulphate and chloride	--	SLS,NAG	Weight loss, polarization study	SLS shows maximum inhibition than NAG	122
123	Iron	--	Ba^{2+},Sr^{2+}, $Ca^{2+}$and Zn^{2+}	DPMG	Electrochemical measurements, AFM and XPS	DPMG/Ba^{2+}/ Sr^{2+}/Ca^{2+}system hindered the anodic iron dissolution, DPMG/ Zn^{2+}system influenced both the anodic & cathodic process	123
124	Tin	NaCl	--	Glycine, Serine, Methionine, Vitamin C and some of their binary mixtures	Impedance polarization & SEM	Glycine, Serine and methionine inhibit dissolution of tin by the charge transfer process while in the presence of cystein and Vitamin C the mixed charge transfer and diffusion control is dominant	124

125	Tin	NaCl	--	Polyacrylamide samples which have different MW sample A,B,C and poly propenoyl	Polarization technique	Polymer D shows the strongest IE	125
126	Steel	H_2SO_4	--	ß-alanine	Polarization study	Corrosion is promoted depends on the concentration of ß-alanine	126
127	Tin cans	Citric acid	--	Nitrate, sucrose and Glycine	Polarization technique	Nitrate treated as weak inhibitor, glycine act as a excellent corrosion inhibitor, sucrose gave IE of 42%	127
128	Carbon steel	Neutral solutions	Zn^{2+}	NPMG	impedance spectra	NPMG/Zn^{2+} system performed as a mixedtype inhibitor	128
129	Copper	HCl	--	V-pph-V,V-oph-V and V-his	Polarization &AC impedance study	V-pph-V give 99.4% IE at20°C	129
130	Steel	H_2SO_4	--	Five amino acids	Potentio-dynamic technique	Maximum protection efficiency was obtained with glutamic acid	130
131	Al	NaCl	--	Arginine, Histidine, Glutamine, Asparagine, Alanine and Glycine	Potentiodynamic technique and cyclic voltammetry	The order of effectiveness of the inhibitors was Arg>His>Glu>Asp>Ala>Gly	131

132	Al 6063 alloy	Deaerated carbonate solution	--	ALAOH,GLYOH, SEROH and METOH	Electrochemical polarization and IR measurements	IE decrease as follow METOH>SEROH>GLYOH>ALAOH>	132
133	16/14 austenitic stainless steel	HCl	--	MET, CIT,AL,GLY, and HPR	Potentio dynamic, Polarization, resistance and Tafel extrapolation methods	Primary passivation potential and the trans passive region shift towards more positive potentials in presence of the studied amino acids	133
134	Aluminium	acidic chloride solutions	--	Aspartic acid	Polarization technique	Aspartic acid acting as mixed type inhibitors	134
135	Zn	--	--	Gelatin, Starch, Poly vinyl alcohol, glycine, L-alanine, L-valine	Pitting corrosion current measurements	L-alanine and gelation can be used safely as retardants for the pitting corrosion of Zn	135
136	Iron	HCl	--	Methionine methyl ester hydrochloride (METOCH3)	Mass loss and polarization methods	METOCH3 has95%of IE	136
137	Steel	different pH	--	Poly aspartic acid	EIS, RCE and coupon immersion	Poly aspartic acid robust corrosion between pH7and pH10	137
138	Copper	HCl	--	Four amino acids	Potentio kinetic study	α-alanine was the most efficient of the four amino acids	138

139	Steel	Different pH	--	Aspartic acid	--	Aspartic acid accelerate corrosion at pH less than ionization constant, above that pH, it acted as a corrosion inhibitor for steel	139
140	Carbon steel	Neutral aqueous solution	--	NPMG	Weight loss, AES and surface analysis	NPMG formed the inhibiting film that protects the base metal	140
141	Mild steel	HCl	--	Amphoteric surfactants derived from aspartic acid	--	At a given concentration of surfactants, the inhibiting action increases with the increase of carbon chain	141
142	Cobalt	H_2SO_4	--	Nineteen amino acids	Polarization method	Best results were obtained with glutamic acid	142
143	Mild steel	H_2SO_4	--	Tyrosine	--	Tyrosine is an effective corrosion inhibitor	143
144	Iron	HCl	--	Twenty-two different common amino acids and four related compounds	Potentio-dynamic Polarization study	Best results obtained with 3,5 di-iodo tyrosine has87% of IE. The best common AA was Tryptophan has 80%of IE	144
145	Mild steel	H2SO4	--	Cysteine, Cystine and methionine	Polarization study	These amino acids act as mixed type inhibitors	145

146	ASTMA-470 steel	NaOH	--	Na//2SiO//3, NaH//2PO//4, Na//;2CrO//4, aniline and its derivatives, tannic acid, L- Phenyl alanine and octadecylamine	Electro chemical methods	Aniline and its derivatives, L-phenylalanine, NaH//2Po/4, Na//2SiO//3, Na//2Cro//4, inhibit the anodic process and octadecylamine inhibits both	146
147	Cadmium	Acetic acid	--	Potassium nitrate potassium dichromate glycine, L-leueine and L- valine, chloral hydrate aniline, P-anisidine thiosemicarbazide potassium permanganate	Electrochemical study	Potassium nitrate potassium dichromate glycine, L-leueine and L-valine have Corrosion acceleration effect. chloral hydrate aniline, P- anisidine thiosemicarbazide act as corrosion inhibitor.	147
148	Steel	Dilute Nitric acid	--	Ammonium thiocyanate, Tryptophan, methionine	--	The result obtained confirm that the good adsorption of a substance is still not a sufficient condition for corrosion inhibition and selecting inhibitors must take into account the structure and stability of the adsorption layer	148

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