CHAPTER II

LITERATURE SURVEY
CHAPTER 2

LITERATURE SURVEY

This Chapter is divided into three sections. The work reported in literature on the corrosion of aluminium in hydrochloric acid and in sodium hydroxide is given in Section I. Section II deals with an account of the inhibition of corrosion of aluminium in diverse aggressive media. If the substances investigated by us as corrosion inhibitors for aluminium — 65S in hydrochloric acid solutions have been investigated as corrosion inhibitors for other metals in diverse corrosive media, such findings are reported in Section III.
SECTION I

CORROSION OF ALUMINIUM IN HYDROCHLORIC ACID AND SODIUM HYDROXIDE

A. HYDROCHLORIC ACID

The corrosion of aluminium in hydrochloric acid does not start immediately because of the slow attack on the oxide film. Oxides of the type $\text{M}_2\text{O}_3$ always display a sluggish reaction with acids. A long period of induction which must elapse before the attack becomes vigorous seems to be connected with the gradual destruction of the skin through dissolution or undermining.

Müller and Löw\(^1\) investigated the corrosion rates of aluminium of different grades of purity in hydrochloric acid. They observed that 99.998% pure aluminium was attacked only by 4.0N hydrochloric acid. The dissolution process is characterised by an incubation period during which the metal does not dissolve, an induction period during which the corrosion velocity increases rapidly and the reaction period during which the reaction velocity becomes constant or falls off. With an increase in acid concentration, the incubation and induction periods become shorter.

Straumanis\(^2\) observed that if 99.998% aluminium is first etched in concentrated hydrochloric acid and then introduced
into more dilute acid, it is immediately attacked as the induction period is eliminated by the prior dissolution of the oxide film, although the final corrosion rate is not greatly altered.

Genet observed that increase in acid concentration, temperature or stirring decreases the induction period. The induction period is shorter for an abraded surface than for a polished one.

Aronson and Yoffe reported that the corrosion of aluminium in hydrochloric acid increases with acid concentration to a maximum up to 6.0N and then decreases rapidly. The corrosion of aluminium in 12.0N HCl is about the same as that in 1.0N HCl. The decrease in rate of corrosion is explained on the basis of the formation of a protective chloride layer.

Müller and Löw reported that the presence of 0.5% impurities reduces the corrosion resistance by 1/7000.

Glistenko studied the corrosion of aluminium in 1.0N hydrochloric acid in the presence of several inorganic compounds and reported that addition of potassium dichromate, silver nitrate, ammonium hydroxide, potassium permanganate, magnesium sulphate, ammonium nitrate, ferric chloride and mercuric chloride accelerate the corrosion of aluminium. An addition of hydrogen peroxide in hydrochloric acid increases the corrosion of aluminium.
Nishiura observed the corrosion of aluminium in dilute hydrochloric acid solutions by loss in weight method as well as by gas evolution method. An addition of 0.5% manganese to aluminium-manganese alloy is beneficial to its corrosion resistance in hydrochloric acid whereas addition of antimony or zinc is not beneficial. Aluminium alloys containing 1.5% manganese and 0.3% chromium were not attacked easily, their corrosion resistance being analogous to that of pure aluminium.

Kuwahara studied the corrosion of aluminium-silicon alloys in 10.0% hydrochloric acid at 20°C and observed that aluminium containing 3.0% silicon is corroded to a greater extent than that containing 0.26% silicon.

Belyaev reported that the corrosion of commercial aluminium in 5.0% hydrochloric acid is accelerated by increasing amounts of impurities especially iron, small amount of titanium does not affect the dissolution rate (less than 0.3%). 0.3% beryllium affects the corrosion only slightly, cobalt and rhenium accelerate corrosion. However, niobium decreases the dissolution rate.

Arora et al. observed that intergranular corrosion of aluminium in 10.0% hydrochloric acid becomes more rapid with increase in copper content, as little as 21 p.p.m. copper gives a significant effect. The effect of copper is greater than that of any other residual element. This might be due to an autocatalytic acceleration produced by copper.
Tavadze\textsuperscript{10} et al. reported that aluminium-titanium alloys completely resist hydrochloric acid in all concentrations at room temperature.

Iinui\textsuperscript{11} et al. stated that corrosion of aluminium in dilute hydrochloric acid (less than 1.0N) is first order reaction in the beginning but gradually changes to second order. The dissolution in less than 0.5N aqueous hydrochloric acid is 1/2 order but in presence of atmospheric oxygen it is of a first order.

\section*{D. SODIUM HYDROXIDE}

Already in the nineteenth century Wohler\textsuperscript{12} had described that aluminium is very strongly attacked by aqueous solutions of alkali and this corrosion was accompanied by vigorous hydrogen evolution.

However, the research work on the mechanism of corrosion of aluminium in alkali began in 1933 with the work of Centnerzwer\textsuperscript{13}, 14 and Schikorr\textsuperscript{15}. According to them, the corrosion process can be represented by the equation

$$\text{Al} + \text{OH}^- + \text{H}_2\text{O} \rightarrow \text{AlO}_2^- + 3/2\text{H}_2$$

According to Straumanis and Braksa\textsuperscript{16}, the reaction can be shown by the following overlapping procedures:

(a) Attack of metallic aluminium through water and formation of aluminium hydroxide.
Anodic reaction:
\[ \text{Al} \rightarrow \text{Al}^{+++} \text{aq}^+ + 3 \text{e}^- \quad (i) \]

Cathodic reaction:
\[ 3\text{H}_2\text{O} + 3 \text{e}^- \rightarrow 3\text{OH}^- + 3/2\text{H}_2 \quad (ii) \]

Hydroxide formation:
\[ \text{Al}^{3+} \cdot \text{aq}^* + 3\text{OH}^- \rightarrow \text{Al(OH)}_3 \quad (iii) \]

the sum of (i), (ii) and (iii) being
\[ \text{Al} + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3/2\text{H}_2 \quad (2) \]

(b) Reaction of aluminium hydroxide which is formed on aluminium surface with the hydroxyl ions of base on the formation of aluminates according to equation
\[ \text{Al(OH)}_3 + \text{OH}^- \rightarrow \text{AlO}^-_2 + 2\text{H}_2\text{O} \quad (3) \]

In the case of a fairly high hydroxyl ion concentration of the attacking liquid, the reaction with pure aluminium takes place according to equation 3. The reaction is very quick and the metal does not retain any surface layer of aluminium oxide.

In the case of lesser concentration of hydroxyl ions (as well as due to a huge consumption of OH ions), there is a tarnishing on the aluminium surface due to a crust of aluminium hydroxide.

Moreover, Schikorr\(^{15}\) has observed that the aluminate which has gone in solution is subjected to a hydrological separation in the course of time (contrast to 3). Therefore, after a
temporary exhaustion of OH$^-$ ions due to reaction No. 3, the corrosive attack due to newly formed OH$^-$ ions becomes stronger again, even though the secondarily formed hydroxide is separated partially from the metal. The corrosion here, therefore follows an extremely inconsistent route. There are alternate periods of visible attack, which changes to a standstill of the reaction. Then, it is possible that the proposed decomposition of Al(OH)$_3$ layer on the middle surface takes place only partly after a genuine aluminate formation according to equation 3.

Bukowiecki$^{17}$ reports that one part of the hydroxide is only colloidal. The aluminate solutions always contain colloidal patches of hydroxide. Under these circumstances, a secondary precipitation of Al(OH)$_3$ in alkali solutions should be replaced at least partially by slow coagulation process.

According to Centnerszew$^{13,14}$ and Schikorr$^{15}$, the removal of the oxide layer on surface of pure aluminium is slower than the electrochemical part of the reactions $2^a$ and $2^b$ so that in case of visible hydrogen evolution type of corrosion, the dependence of corrosion intensity on the purity of metal is only small. The more than usual hydrogen evolution is due to two factors:

1. The corresponding dependence of corrosive attack of alkali on purity of metal is only small.

2. In the corrosion of strong hydrogen type of evolution, varying hydroxide formation of metallic phase.
According to other authors such as Arndt, Muller, Strawnmann, and Streicher, the remarkable influence of metal composition exists when the samples are of purest aluminium and when sufficient quantity of the metal was used to obtain an exhaustion of OH⁻ ions during the corrosion test. Therefore, it has to be assumed that according to the metal quality, either step 2 or 3 of the corrosive process becomes now rate determining. Since the solubility of OH⁻ also can depend upon the chemical composition of the base metal.

Especially impressive are the results of research of Streicher. He reports that the intensity of the aluminium attacking effect by 0.3N NaOH solution increases with the purity in the following order: 99.99, 99.99, 99.87, 99.84, 99.01 and 99.5.

The pollution of aluminium by iron at once increases the corrosion. The next is the addition of copper. For the remaining elements, the attack can be substantially accelerated (in the case of 99.998 aluminium) by addition of iron, and CaCl₂. Debay also observed that the behaviour of ferric salts is analogous to that of cupric salts, the former being more aggressive. Streicher had observed that the plot of corrosion rates of aluminium against concentration of sodium hydroxide is not linear, there being maximum corrosion at 220 gms/liter concentration of sodium hydroxide. Debay remarked that the electrical conductivity of sodium hydroxide solutions shows a similar maximum and the corrosion intensity is nearly proportional to conductivity values.
In the tests of Straumannni and Brakes, with 99.998% pure aluminium, it has been proved that the Freundlich values of corrosion intensity is scattered because the very few pollutants are very irregularly distributed. These authors also observed a sudden jump in corrosive activity at 160 g/liter concentration.

According to Jablonski and Streicher, the rate of dissolution of aluminium in alkalies is not affected by stirring the solution, but temperature has a very marked effect, each increase of 10°C in the temperature raises the solution rate by a factor of two or more.

Schikorr established that the solution rate of aluminium in alkalies is almost independent of the purity of the metal, and on the basis of his experiments, concluded that the solution rate is determined not by the formation of microgalvanic cells, but most probably by the production of a film of amorphous hydroxide on the metal surface and its subsequent slow dissolution. The cathodic process in which hydrogen is evolved is of secondary importance.

According to Putilova, the solution rate for aluminium in sodium hydroxide is given in terms of concentration by the equation

\[ c = k \sqrt{c} \]  

(1)

where \( c \) is the alkali concentration and \( k \) the rate constant of the reaction.
This can be extended to solutions of weak bases by taking into account the degree of dissociation $\alpha$:

$$p = k_1 \sqrt{\alpha} c$$  \hspace{1cm} (3)

Since $\alpha^2$ for weak bases is inversely proportional to their concentration, equation (2) may be written in the form

$$p = k_2 \sqrt{c}$$  \hspace{1cm} (3)

where $k_2$ is a constant depending upon the properties of the electrolyte. Within certain narrow limits of alkali concentration, the relationship between $p$ and $c$ may be linear.

Rasov and Trainina\textsuperscript{25} reported that the approximate corrosion rate of aluminium in alkalis may be calculated by the equation

$$p = k \cdot c \cdot 2^{1/10}$$  \hspace{1cm} (4)

where $p$ = corrosion rate in g/m$^2$/sec.

$k =$ constant equal to the corrosion rate at 40\textdegree C

c = concentration of NaOH in g mole/l

$\eta(t - 40/10) =$ temperature coefficient of the reaction

Goldowski\textsuperscript{25} investigated the influence of the diameter of cylinders on the corrosion of aluminium in sodium hydroxide. The loss of weight decreased with increasing diameter.

Muller, Low and Steiger\textsuperscript{27} studied the corrosion rates of 99.998\% pure aluminium in 1.0N sodium hydroxide. The corrosion rate was expressed by the local current which was measured hydrogen
lowest values of the local current are obtained if an external current is applied, probably owing to passivity within the pores of the cover layer. The anode potential of the aluminium and the overvoltage potential of the hydrogen are constant at -1.65 and -1.1 volt respectively, resulting in a potential difference of the local current of 0.45 volt. The resistance of the pores and of the layer is essential.

Perryman reported that the grain boundary attack of sodium hydroxide on aluminium had been attributed to the high energy of the grain boundary material by earlier workers. Perryman investigated the effect for high purity aluminium-iron alloys with upto 0.055% iron. He found that the results can be explained on the assumption that Fe segregates to the grain boundary in solid solution.

Dionisev reported that the rate of corrosion of aluminium in sodium hydroxide was proportional to square root of its concentration. Corrosion of aluminium takes place with mixed cathode anode control.
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SECTION II

INHIBITORS FOR THE CORROSION OF ALUMINIUM AND ALUMINIUM BASE ALLOYS

Since the publication of the excellent review by Eldridge and Mears\(^1\), numerous articles have been published on inhibitors for the corrosion of aluminium. Pritchett and Roebuck\(^2\) have discussed classes of various inhibitors for aluminium and have given a list of some inhibitors (41 ref). This Section deals with inhibitors reported in literature up to 1967 for the corrosion of aluminium in (I) Water, (II) Seawater and salt solutions, (III) Alkaline solutions, (IV) Acidic solutions, (V) Ammonical solutions, (VI) Organic substances, (VII) Atmosphere and (VIII) Miscellaneous media.

I. CORROSION INHIBITORS FOR ALUMINIUM AND ALUMINIUM BASE ALLOYS IN WATER

Goddard\(^3\) reports that soft waters are least corrosive to aluminium, however, the major factors influencing the corrosivity of water to aluminium are pH, the amount of copper, bicarbonate, chloride, sulfate and oxygen contained in water. Goddard\(^4\) further states that the corrosion of aluminium in aggressive water is usually complicated by the presence of other metals in the system.

Dunstan and Hill\(^5\) used chromates to retard the corrosion of aluminium in water. Rohrig\(^6\) reported that sodium chromate
reduces the corrosion of aluminium in tap water as well as in slightly acidic or alkaline waters. Eldridge and Mears\textsuperscript{1} report that chromates inhibit the corrosion of aluminium in water as chromates improve the film by deposition of Cr\textsubscript{2}O\textsubscript{3} along with Al\textsubscript{2}O\textsubscript{3} in the breaks of original oxide film. Elder\textsuperscript{7} reported that simultaneous addition of 0.2-1.0\% sodium chromate, 0.25\% sodium benzoate and 0.5 to 1\% hexamine\textsuperscript{7} and maintaining the pH between 7.5 and 10 or adding 2 amino 2 methyl 1 propanol\textsuperscript{8} in place of hexamine and adjusting the pH to 10 for retarding corrosion of aluminium in water. Neumann\textsuperscript{0} reported that chromate-phosphate mixture is more effective than chromate alone and recommended the use of a mixture of 20-25 p.p.m. chromate and 4-5 p.p.m. polyphosphate at pH 6.5-7.5. Grover et al.\textsuperscript{10} reported that if chromates are used as inhibitors for corrosion of aluminium in tap water, their concentration should be kept below 0.3 per cent to avoid pitting corrosion.

Callender\textsuperscript{11} observed that an addition of 0.8 p.p.m. potassium dichromate to water protects aluminium from corrosion by formation of a film over the metal surface. It was observed that at concentrations greater than 0.006\% sodium nitrate protects aluminium and its alloys in water, but it is not effective at lower concentrations\textsuperscript{11}. Eldridge and Mears\textsuperscript{1} observe that nitrate acts as a builder of Al\textsubscript{2}O\textsubscript{3} film.

Rowe\textsuperscript{12} found sodium nitrite to be an excellent inhibitor for aluminium in engine cooling systems.
Hatch patented the use of mixture of sodium nitrite, borax, benzotriazol etc. to prevent the corrosion of aluminium in closed water systems.

Eldridge and Meares reported the use of sodium pyrophosphate and sodium hexametaphosphate to inhibit the staining of aluminium in boiling tap water. Balistrick observed that sodium metaphosphate protects aluminium from corrosion in distilled or tap water.

Wormwell and Mercer reported that at 0.05% concentration, sodium benzoate completely protects aluminium from corrosion in distilled or tap water at room temperature. Grover et al. reported that sodium benzoate gives partial or negligible protection to aluminium in tap water.

Kiyuchnikov et al. reported that at 0.0001 mole/liter concentration, sodium adipate and dibutyl adipate effectively retard the corrosion of aluminium in distilled water for 2 to 12 months.

Grover et al. reported that sodium silicate satisfactorily protects aluminium in tap water. Pritchett recommended the use of a mixture of sodium silicate and sodium polyphosphate at pH 8.5-9.5 for prevention of corrosion of aluminium in water.

Tabakoff reported that circulating water containing 0.1 gm/kg colloidal silica and borax does not corrode aluminium even after two months of continuous use.
Rehrig\textsuperscript{20} observed that oil which emulsifies in water retards the corrosive action of water by formation of a thin oil film on metal surface which protects aluminium even against boiling water. Kempf and Daugherty\textsuperscript{21} observed that soluble oils retard the corrosion of aluminium in soft waters. Rowe\textsuperscript{12}, however, observed that soluble oils give unsatisfactory results in tests with couples of dissimilar metals.

George\textsuperscript{22} patented the use of water soluble salt of glucoside derived from a succulent plant for retardation of corrosion of aluminium and its alloys in aqueous media.

Woods\textsuperscript{23}, et.al. reported that an organic phosphorous compound, Virbecopet-30 inhibits the corrosion of aluminium and its alloys in static and circulating solutions, and in stirred water. Such protection is also afforded to galvanically coupled aluminium in these media.

Zimmerman\textsuperscript{24} patented the use of hydrazine as an inhibitor for the corrosion of aluminium and its alloys in steam generators and aqueous heat exchange systems. The presence of small amounts of iodide, bromide or alkali or ammonium salts of oxyacids enhanced the inhibitor action of hydrazine.

Morehouse\textsuperscript{25} patented the use of organosilicon compounds with an amino group joined to silicon atom by a saturated hydrocarbon chain as inhibitors for corrosion of aluminium and its alloys in aqueous solutions.
II. CORROSION INHIBITORS FOR ALUMINIUM AND ALUMINIUM BASE ALLOYS IN SEA WATER AND IN SALT SOLUTIONS

Addition of 0.2% sodium chromate inhibits corrosion of aluminium in sea waters. Eldridge and Mears observed that for water containing 100 p.p.m. salts, chromates are effective inhibitors. In synthetic tap water, strontium chromate is effective to an extent of 80%.

Addition of 0.01% or 0.1% potassium dichromate prevents the staining of aluminium in dilute salt solutions (100 p.p.m.) containing 5-50 p.p.m. cupric chloride.

It is reported that between pH 6-12, sodium benzoate inhibits the corrosion of aluminium in 0.03% sodium chloride but it is less effective than the corresponding nitrite or chromate.

Eldridge and Mears observed that silicates and soluble oils are effective inhibitors for corrosion of aluminium in water containing 100 p.p.m. salt. Zinc nitrate, mercaptobenzthiazol, agar agar, dextrine and gum arabic exhibit some protective action whereas potassium nitrate accelerates corrosion.

4 alkyl pyrocatechols protect aluminium and its alloys against corrosion in sea water. The side chain attached to the position No. 4 of the benzene nucleus must be a straight chain alkyl radical with 16 to 18 carbon atoms.

The inhibition of corrosion of aluminium in 3% NaCl solution by octadecylamine salt of maleinated methyl olate (I),
acid (II) and monooester of maleic acid and octadecylamine (III) was investigated by Sato who observed that the order of efficiency is I > III > II.

Esters of alcohols containing 3-5 carbon atoms with acids containing 12-20 carbon atoms have been reported as corrosion inhibitors for aluminium in sea water.

Fujii and Aramaki studied amines, acid amides and mercaptans as inhibitors for corrosion of aluminium in 3% NaCl solutions at 30°C. These inhibitors function by adsorption on the metal; the adsorption process interferes both with anodic and cathodic reactions.

Bruno et al. studied the inhibition of the corrosion of aluminium in sodium chloride solutions by quaternary compounds having the general formula 3 CaO, Al₂O₃, CaX₂, H₂O (X = picrate, chromate or manganate) the protection is afforded for a period of sixty days. It was found that the chromate anion in the place of X gave best protection. Results are probably extendable to aluminium imbedded in cement not containing CaCl₂.

Richaud studied inhibition of the corrosion of aluminium in chloride solutions by potentiokinetic methods; and found that the best protection is afforded by a mixture of potassium, barium and zinc chromates.

Lepina and Latyns observed the inhibition of corrosion of aluminium by colloidal substances. In potassium chloride
solutions, the colloidal particles are positively charged and are not precipitated on anodic areas. In potassium sulphate solutions, the particles are positively charged or neutral, and precipitate very close to aluminium surface retarding its corrosion. In potassium ferrocyanide solution, the colloidal particles are negatively charged and block the anodic areas directly, therefore, a stronger inhibition is observed.

Bohner and Rohrig observed that silicates effectively retard the corrosion of aluminium in calcium chloride and in sodium acetate solutions. Sodium chromate has been suggested as an inhibitor for the corrosion of aluminium in magnesium oxychloride.

The corrosion of aluminium in potassium cyanide can be prevented by sodium silicate.

Sodium silicate and sulfur have been suggested as inhibitors for the corrosion of aluminium in sodium sulfide solutions.

Sodium dichromate prevents the corrosion of aluminium in sodium trichloroacetate.

Richaud studied the inhibition of corrosion of aluminium in 0.1M sodium sulfate solutions at different pH and in presence of chloride by sodium dichromate, sodium arsenate, sodium molybdate, sodium metaborite, sodium nitrate, sodium silicate,
ammonium vanadate and nicotinic acid. The inhibitive action was pH dependent.

III. CORROSION INHIBITORS FOR ALUMINIUM AND ALUMINIUM BASE ALLOYS IN ALKALINE SOLUTIONS

When the metal hydroxide has amphoteric properties, the metal is strongly attacked by alkali. Thus, aluminium is severely corroded by alkaline solutions accompanied by hydrogen evolution. However, pickling of aluminium articles in alkaline solutions is a very widely applied practice in industry. Prior to anodisation, aluminium parts are degreased by dipping in 5% caustic soda solution. Finding effective inhibitors of the corrosion of aluminium in alkaline solution is, therefore, essential but rather difficult, in the light of Antropov's remark that 'for a corrosion process occurring at a very negative potential, as for example, dissolution of aluminium in alkalies, all organic compounds will be ousted from the electrical double layer and it will be difficult to find an effective inhibitor.'

Alkalies:

Centerschwer observed that perchlorate ions retard the corrosion of aluminium in alkalies but halides, sulfates, nitrate and chlorate ion accelerates it.

The use of hydrogen peroxide for the prevention of corrosion of aluminium by alkaline solutions has been patented. Caprioglio observed the inhibitor action of hydrogen peroxide
for the corrosion of aluminium in sodium hydroxide solutions between pH 9-11 at different temperatures. At higher inhibitor concentrations, it affords a good protection but at lower concentrations, a black unprotective film is formed over the surface which cracks, and pitting corrosion of the exposed area occurs. Krarachankov et al. reported that hydrogen peroxide inhibits the corrosion of aluminium in potassium hydroxide solutions containing chloride or nitrate.

Collari, Reschke and Neunzig and Streicher reported the use of potassium permanganate for the inhibition of corrosion of aluminium in sodium hydroxide solutions. Collari reports that permanganate exercises protective action by formation of a coating of oxides of manganese. Neunzig observes that inhibitor action of KMnO₄ is greater than that of Na₂CrO₄.

According to Streicher, the accelerating action of small amounts of potassium permanganate was due to the formation of a brown product which acted as a cathode to establish local cells. With increase in permanganate concentration, anodic areas and dissolution rates decreased. The thick layer then impedes contact of the solution with the metal surface. Ramachar, however, reported that the efficiency of potassium permanganate is quite low.

Reschke and Neunzig observed that sodium chromate retards the corrosion of aluminium in sodium hydroxide solutions.
Tanaka et al. also studied sodium chromate as an inhibitor for the corrosion of aluminium in alkaline media.

Cesana et al. observed that chromates of cations of group II are more effective inhibitors for aluminium in neutral and alkaline media. A 0.01 to 0.03M Na₂CrO₄ solution becomes more corrosive to aluminium with time, due to the removal of H₂CrO₄ leaving a solution of NaOH, whereas Mg and Ca chromates are unchanged by depletion.

Klimov observed that sodium nitrite accelerates the corrosion of aluminium in alkaline media.

Rhodes and Berner report that common inorganic salts of alkali metals accelerate the corrosion of aluminium in alkalies; at higher inhibitor concentrations, sodium metasilicate inhibits the corrosion but at lower concentrations pitting of the surface occurs. Rohrig observed that at amounts considerably exceeding the alkali concentration, sodium metasilicate acts as an inhibitor.

Wildbrett et al. observed that the corrosion of pure aluminium at high temperature and pressure by alkaline solutions of pH 11 can be prevented by addition of sodium metasilicate.

Dessai and Dessai reported that sodium alginate inhibits the corrosion of aluminium in sodium hydroxide solution to an extent of 75%. The corrosion process of aluminium is essentially under mixed control with a predominant action on
on anodic areas. In presence of sodium alginate, anodic polarisation increases significantly. A synergistic action of sodium alginate with potassium selenate and sodium perborate was also observed, the efficiency increasing to 92%.

Rhodes and Benner report that alcohols and phenols do not protect aluminium in alkaline media.

Rohrig reported that 0.75% agar agar retards the corrosion of aluminium in caustic solutions. It has also been studied as an inhibitor for the corrosion of aluminium in sodium hydroxide solutions by Ramachar et al. In 0.3N NaOH, at 32°C, for 1-6 hours, the efficiency of agar agar was 77-90% for aircraft aluminium-zinc alloy, 24-30% for aircraft aluminium-copper alloy, 71% for SIB-III alloy (98.5% Al) and 80% for pure aluminium. For aluminium manganese alloy, in 0.1-0.6N NaOH, the efficiency of agar agar was practically constant with increase in alkali concentration.

Tanaka et al. reported that amylase inhibits the corrosion of aluminium in alkaline solutions by adsorption on the aluminium surface as a thin layer.

The efficiency of dextrin in sodium hydroxide solutions is 40-42% for 98.5% aluminium, aluminium-iron-magnesium alloy (92% Al), aluminium-zinc-copper manganese alloy (86% Al), aluminium-iron-silicon alloy (98.8% Al). Dextrin exercises its inhibitor action by influencing anodic reaction. For
aluminium manganese alloy in 0.1-0.6N alkali at 32°C. for 3 hours the efficiency of dextrin decreases with increase in alkali concentration.59, 60-62.

At 4-8% concentration, gelatin protects pure aluminium in 4% caustic soda to an extent of 90%.52.

Streicher48 as well as Ramachar et.al.44, 46, reported the use of gelatine for retarding the corrosion of aluminium in alkaline solutions.

In 0.3N sodium hydroxide solution at 32°C, for 1-6 hours gelatin protects pure aluminium (74%), SIB-III alloy (53-62%), aircraft zinc alloy (75%) and aircraft copper alloy (30-50%).56. Subsequently, Ramachar et.al. reported that gelatin is not as good an inhibitor as reported in literature59, 61.

Gum arabic has been reported as an inhibitor for the corrosion of aluminium in alkaline medium by Ramachar et.al.44, 46, and by Tanaka47. According to Tanaka49, gum arabic acts by adsorption on the surface of aluminium. In 0.3N alkali, for 1-6 hours duration at 33°C, the efficiency values of gum arabic in pure aluminium, SIB-III alloy, aircraft zinc and aircraft copper alloy are respectively, 84, 56-57, 84-91 and 58-82%.56. Gum arabic has been reported as an excellent inhibitor for corrosion of aluminium in alkaline medium58-61.

De Muller63 reported that at 40°C, gum tragacanth retards the corrosion of aluminium in 0.3N sodium hydroxide solutions
to an extent of 83 to 87%. Tanaka reported that gum tragacanth is adsorbed over metal surface forming a thin protective layer.

Ramachar et al. studied glue as an inhibitor for corrosion of aluminium in sodium hydroxide solutions but it was not found to be very efficient.

Ramachar et al. reported that in 0.3N sodium hydroxide solutions, the order of efficiencies of these colloids were as follows:

1. Commercial aluminium (82% Al), and SIB-IHI alloy (99.5% Al), Agar agar > Gum arabic > gelatine.

2. Aircraft zinc alloy (86% Al): Gum arabic > Agar agar > Gelatine > Glue.

3. Aircraft copper alloy (91% Al): Gum arabic > Glue > Gelatine > Agar agar.

Subsequently Ramachar et al. reported that in 0.1 to 0.6N sodium hydroxide solutions, the order of efficiency was Agar agar > Gum arabic > Dextrin > Gelatine > Glue. According to him, mixed inhibitors offered no advantage over single inhibitors.

Rhodes and Berner reported that at 18% concentration, glucose completely protects aluminium in 4% caustic soda. Ramachar, however, reported that the efficiency of glucose
Saponin has been reported as a corrosion inhibitor for aluminium in alkaline solutions. Tanaka reported that in the presence of Saponin, a thick and separable film is formed over the aluminium surface.

The use of sulfite liquors for inhibition of corrosion of aluminium in alkaline media was reported by Klimov, as well as by Balezin et al. Sulfite liquors containing traces of cadmium sulfate afford good protection to aluminium. It was postulated that the amorphous thin film formed over the metal surface by reaction of sodium aluminate and sulfite liquor becomes stronger when seeds of CaSO₄ crystals are coated with liquor. Khrustov observed that Sulphite cellulose liquors inhibit the corrosion of aluminium in alkaline medium due to the presence of lignosulphonic acids. Beyond 2N NaOH, the inhibitor action abruptly decreases. A remarkable fact is that while the corrosion rate of aluminium in sodium hydroxide solution increases strongly with temperature, the increase in rate is very small in the presence of this inhibitor.

Titova reported the use of a CEB (a byproduct of coke industry) as an inhibitor for corrosion of aluminium in 0.6N NaOH.

Negroev et al. reported that the use of sodium napthenate.
alkyl sulfates, a mixture of amides of napthenic acid, and Katapin A, Sulfoton III for retardation of the corrosion of aluminium in alkaline solutions. Ions formed by the dissociation of alkyl aryl sulfonates and aluminium ions formed by redissolution of aluminium react to form products which are adsorbed on metal surface to form a hydrophobic film.

According to a British Patent, the sulfonation products of nitrites of fatty acids having 6-30 carbon atoms inhibit the corrosion of aluminium in alkaline solutions.

In a further communication Negreev et. al. reported that sulfonil derivatives of monostanolamine, aniline, hexamethylenediamine, retard the corrosion of aluminium in alkaline clay suspensions.

Antropov et. al. reported that mixtures of casein, albumin and alkali sulfites retard the corrosion of aluminium in sodium hydroxide solutions.

Cheng reported that KKH-2, a byproduct of coke manufacture (containing Phenol, Catechol, Resorcinol, Cyanides, Sulfo cyanide, etc.) inhibits the corrosion of aluminium in caustic soda solutions, the efficiency being 79.8% in 0.1 and 0.2N NaOH. It is not very efficient at higher alkali concentrations.

Klimov reported PB-8 and peat extracts as inhibitors for the corrosion of aluminium alkalies.
Horner et al. investigated triphenylarsin oxide, benzylisochroman bromide, triphenylsulfonium hydrogen sulfate, diphenyldibenzylphosphonium chloride, diphenyldithiophosphinic acid, thiourea, o-tolylthiourea, mercaptobenzothiazole, as inhibitors for the corrosion of aluminium in 0.1N sodium hydroxide solutions; however, the efficiency was very low, i.e. less than 20%. They observed that thiourea, o-tolylthiourea and mercaptobenzothiazole act by the formation of zwitter ions and are adsorbed over cathodic areas.

Lichtenberg reported that several organic dyes inhibit the corrosion of aluminium in alkaline solutions.

An extract from Sisalana containing glucosides, sugars, waxes, colouring matters, etc. is emulsifiable in water and is reported to be an excellent inhibitor for the corrosion of aluminium in alkaline media. The inhibitor suppresses both anodic and cathodic reactions.

Hagakawa et al. have made extensive studies on the inhibition of corrosion of aluminium in alkaline media, testing various classes of organic compounds as inhibitors. Hagakawa and Ida studied o-hydroxy are derivatives of cresol, resorcinol, α-napthol and β-napthol as inhibitors for corrosion of 99.8%. 

Aluminium in basic medium compounds which could form metal chelates with aluminium inhibit the corrosion process, whereas those which cannot easily form metal chelates with aluminium showed little inhibition. It was observed that azo cresol was the best inhibitor and afforded over 90% protection to aluminium in 0.05N NaOH.
Subsequently, Hagakawa et al. studied hydroxyquinoline derivatives as inhibitors. Hydroxyquinoline and hydroxyquinaldine which form chelates with aluminium in an alkaline medium, inhibit the corrosion whereas quinoline, quinaldine and 8 methylquinoline which do not form such chelates, do not retard the corrosion.

Hagakawa et al. observed that o-aminophenol acts as an inhibitor for corrosion of aluminium in alkaline medium but the action is not due to formation of chelate compound. m, and p aminophenols as well as toluidines act as inhibitors due to sorption on the metal surface by polarity of amino radical.

β-diketones such as acetylacetone, benzylacetone, trifluoroacetone, 1-(2 furonyl)-3, 3, 3 trifluoroacetone, 1(2-thionyl) 3, 3, 3 trifluoroacetone, methylpropylketone were studied as inhibitors for the corrosion of aluminium in alkaline media by Hagakawa et al., who report that compounds possessing large hydrophobic and electronegative groups show a high inhibitor action.

Hagakawa reported that at pH > 10.5, polycarboxylic acids (EDTA, nitrotricarboxylic acid, iminocarboxylic acid and glycine) which form easily soluble compounds with aluminium do not inhibit the corrosion of aluminium in alkaline medium but accelerate it. However, subsequently Hagakawa observed that o-hydroxyazo-benzene sulfonic acids which form hardly soluble chelates with aluminium inhibited its corrosion in alkaline
solutions of pH 10.5. However, chelating agents with a similar structure but having a sulfonic acid group in the molecule accelerated the corrosion process under the same conditions.

Hagakawa et al., studied alizarin derivatives as inhibitors for the corrosion of aluminium in alkaline media and observed that the inhibitor action is due to chelate formation.

Carbonate solutions:
Seligman and Geller reported that sodium silicate completely inhibits the corrosion of aluminium in carbonate solutions. Wolf and Tuxhorn reported that fluosilicates are effective inhibitors for the corrosion of aluminium in carbonate solutions. Thomas and Degorge also reported the use of silicates and fluosilicates as inhibitors for the corrosion of aluminium in sodium carbonate solutions. Aldridge and Meare observed that silicates with a high ratio of silicate to soda are most effective inhibitors. Negreov et al. reported that soluble silicates are excellent retarders for the corrosion of aluminium in sodium or potassium carbonate solutions. The inhibitive action of silicate increases with increase in silica content.

Ammar et al. observed that the corrosion of aluminium in 0.1N sodium carbonate is completely retarded by $5 \times 10^{-4}$M potassium dichromate. Hydrogen peroxide, borax and disodium
hydrogen phosphate retard the corrosion at higher inhibitor concentrations but are accelerators at lower concentrations.

Other Alkaline media:
Koch reported that the corrosive action of polyphosphates is proportional to their complex forming activities and it increases in the order of pyrophosphate, tripolyphosphate, metapolyphosphate. Silicates inhibit the corrosion of aluminium by polyphosphates.

Silicates have been suggested as inhibitors of corrosion of aluminium in alkaline phosphate solutions by Seligman, Eldridge and Mears, Degorges.

For the prevention of corrosion of aluminium in alkaline bleaching liquors, addition of hydrogen peroxide, sodium perborate and sodium silicate has been recommended.

The use of sodium silicate has been recommended for the prevention of corrosion of alkali sulfide dye liquors, alkaline soap solutions, tooth pastes, shaving creams, etc.

Churchill, as well as Blough and Churchill observed that 0.07 to 0.4% sodium silicate is an effective inhibitor for the corrosion of aluminium in alkaline soap solutions, tooth pastes, shaving creams, etc.

It has been observed that the addition of 2-(3-carboxyl phenyl) amino-4 methylphenol retards the corrosion of aluminium.
and its alloys in alkaline solutions and in alkaline pastes such as tooth pastes.

IV. CORROSION INHIBITORS OF ALUMINIUM AND ALUMINIUM BASE ALLOYS IN ACIDS

(a) General:
Sulfonation products of nitrites of fatty acids having 6 to 20 carbon atoms inhibit the corrosion of aluminium in acidic medium.

Colgate reported that 2 napthoquinoline, acridine and 9 phenyl acridine excellently protect aluminium in weak acids.

(b) Hydrochloric acid:
Siewertz and Lueg reported that alkaloids retard the corrosion of aluminium in hydrochloric acid.

Siewertz and Lueg reported that at 0.0025M concentration, strychnine affords 25% protection to aluminium in 1N HCl. Strychnine affords 60-94% protection to aluminium-zinc alloy in 0.5N hydrochloric acid for 1-3 hours. It acts by influencing the cathodic reaction. It affords more than 95% protection to aluminium-copper alloy (81% Al) in 1N HCl for 1-3 hours.

Quinine hydrochloride was found to be a satisfactory inhibitor for aluminium-copper alloy (81% Al) in 1N HCl, the efficiency being > 95%. Quinine hydrochloride affords 70-90% protection to aluminium-zinc alloy in 0.5N HCl.
It is possible to afford complete protection to aluminium in hydrochloric acid by impressing low cathodic currents in presence of quinine hydrochloride.\textsuperscript{118, 119}

Lichtenberg\textsuperscript{78} reported the use of nicotine sulfate for the prevention of corrosion of aluminium in hydrochloric acid.

In \(1\text{M} \text{HCl}\), for 1-6 hours, nicotinic acid affords 84\% protection to 99.8\% Al alloy.\textsuperscript{104} 81-85\% protection to aluminium-manganese alloy\textsuperscript{103} (93\% Al). Nicotinic acid protects aluminium-zinc alloy (96\% Al) to an extent of 78-96\% in 0.5\text{M} \text{HCl} and to an extent of 85-93\% in 1\text{M} \text{HCl}.\textsuperscript{114, 115} Aircraft aluminium-copper alloy (91\% Al) is protected in \(1\text{M} \text{HCl}\) to an extent of 90-98\%\textsuperscript{113, 114, 118, 119}. Nicotinic acid is an excellent inhibitor for aluminium\textsuperscript{105, 111, 116, 117, 127, 128, 128A}. Nicotinic acid functions by influencing the cathodic reaction.\textsuperscript{129}

Complete protection can be afforded to 99.5\% aluminium in 1.28\text{M} \text{HCl} by a combination of 3 gms/liter nicotinic acid and 0.024 amp/cm\textsuperscript{2} cathodic current.\textsuperscript{129}

Jenckel and Waltman\textsuperscript{132} reported that at 0.003M concentration, acridine and \(\beta\) phenyl acridine afford more than 97\% protection to aluminium in \(2\text{M} \text{HCl}\). Aronson\textsuperscript{133} and Yoffe studied acridine bases as corrosion inhibitors for aluminium in hydrochloric acid and observed that while acridine protects aluminium to an extent of 92\%, substitution by sulphur
increases, inhibitor activity. Brooks$^{134}$ also reported acridine derivatives as corrosion inhibitors for aluminium in HCl.

The efficiency of acridine in 1N HCl for 1 to 6 hours is 98% for SIB-IIH alloy (90.5% Al)$^{56}$, 98% for commercial aluminium (92% Al)$^{56}$, and 97-98% for aircraft aluminium copper alloy (91% Al)$^{56}$, $^{113}$, $^{114}$, $^{118}$, and 97-98% for aircraft zinc alloy$^{114}$, $^{118}$. Acridine leaves an adherent, brown deposit$^{56}$. For aluminium manganese alloy (92% Al), the efficiency was more than 97% in 1N HCl for 2-6 hours$^{103}$. The corresponding value for aluminium zinc alloy in 0.5N HCl (96% Al) being 94-99%$^{109}$, $^{114}$, $^{119}$. Acridine is an excellent inhibitor for aluminium$^{103}$, $^{107}$, $^{110}$, $^{127}$, $^{128}$.

Jenekel$^{135}$ and Brauer reported that $\beta$-napthoquinoline inhibits the corrosion of aluminium in 3-8N hydrochloric acid at 25-50°C, by decreasing the surface tension of the medium and by increasing the effective potential. Jenekel$^{132}$ and Vollman reported that 0.003M $\beta$-napthoquinoline and 2-phenylquinoline affords more than 97% protection to aluminium in 1N HCl. Brooks$^{134}$ reported that quinoline derivatives retard the corrosion of aluminium in hydrochloric acid.

Geller$^{136}$ studied amines as inhibitors for the corrosion of aluminium in hydrochloric acid solutions and observed that methyl, dimethyl, ethyl, diethyl, triethyl, propyl, butyl
and amyl amines afford temporary protection to aluminium in 1 to 5% HCl to an extent of 90% or more. The protection is roughly proportional to nitrogen concentration and to the chain length of the hydrocarbon radical. The efficiency diminishes with increase in time and temperature. Colgate reported that 1% concentration of methyl, ethyl, propyl and butyl amines are effective inhibitors for corrosion of aluminium in HCl, but the protection decreases as temperature rises.

Complete protection can be afforded to 99.5% aluminium in 1.25N HCl by 2.5 gms/liter methylamine and 0.064 amp/cm² cathodic current or 2.8 gms/liter ethylamine and 0.032 amp/cm² cathodic current.

Butylamine satisfactorily retards the corrosion of aluminium-manganese alloy in 1-2N HCl at 32°C, the efficiency being 15-75%. For pure aluminium, the efficiency of butylamine ranges from 63 to 88%, the optimum inhibitor concentration being 0.5 gms/liter. The efficiency of butylamine is less than that of dibutylamine and tributylamine.

The efficiency of dibutylamine in hydrochloric acid ranges from 40-90%. For pure aluminium in 1.25N HCl, the optimum inhibitor concentration is 0.5 gms/liter, the efficiency being from 80 to 87%.

Tri-n-butyl amine was studied as an inhibitor for the corrosion of pure aluminium in HCl. It shows a significant inhibitor...
action upto 3 hours. Inhibitor efficiency increases with increase in inhibitor concentration upto 0.5 gms/liter and then becomes constant.

The order of efficiency of butylamines is tri-n-butylamine > di-n-butylamine > n-butylamine. All the substances exercise the inhibitive action by influencing the cathodic reaction.

Brook reported hexamine as an inhibitor of the corrosion of aluminium in hydrochloric acid. Sheth and Ramachar studied hexamine as an inhibitor of corrosion of 99.5% aluminium in HCl and observed that it acts by influencing the cathodic reaction.

Lichtenberg reported that colloids protect aluminium in hydrochloric acid.

Dextrine protects aluminium manganese alloy (92% Al) to an extent of 73-84% in 1N HCl for 3-4 hours. For SIB-88 alloy (99.5% Al) the efficiency of dextrine ranged between 38 and 62%. With time, efficiency decreased for 2 hours and was constant thereafter. For aluminium zine alloy, its efficiency is only 40% in 1N HCl, for 1 hour.

Dextrine is a good inhibitor for aluminium in HCl. It is possible to obtain complete protection by a combination of low impressed cathodic current and inhibitor. Thus, 99.5% aluminium is completely protected.
in 1N hydrochloric acid for 3 hours by 2 gms/liter dextrine and 0.032 amp/cm² cathodic current. De Angelis reported that tannic acid or colophony inhibit the corrosion of 99.0% aluminium in 1N hydrochloric acid. At 25, 50, 75 for 1 to 10 hours, both substances afford protection to an extent of 90%. In a subsequent communication he observed that tannic acid exercises its inhibitor action by influencing both cathodic and anodic reactions, because it gets adsorbed on the metal surface generally.

Tannic acid protects aluminium manganese alloy in 0.5-4.0N HCl at 32°C to an extent of 80-88%. It also inhibits the corrosion of 99.5% aluminium in 0.5-1.5N HCl.

De Angelis studied Phenol, Pyrocatechol, Resorcinol and Hydroquinone as inhibitors of the corrosion of 99% Al in 1N hydrochloric acid. Efficiencies of the inhibitors at lower concentrations are in the order, resorcinol > hydroquinone > pyrocatechol > phenol whereas at higher solutions the order is changed to hydroquinone > phenol > pyrocatechol > resorcinol. He also tested pyrogallol, phloroglucinol, α naphthol and β naphthol as corrosion inhibitors for aluminium in 1.0N HCl.

Jablonský and Pierschalski reported that 0.005N thiourea protects aluminium in 1.4N hydrochloric acid to an extent of 75%. The efficiency of thiourea in 2N HCl for 1-6 hours is
is 94% for commercial aluminium (91% Al)\textsuperscript{56}, 90.31% for SIB-III alloy (90.5% Al)\textsuperscript{56},\textsuperscript{104}, more than 94% for aircraft copper alloy (88% Al)\textsuperscript{56},\textsuperscript{113},\textsuperscript{114},\textsuperscript{118}, and more than 90% for aircraft zinc alloy (91% Al)\textsuperscript{56},\textsuperscript{113},\textsuperscript{114},\textsuperscript{118}, and 94% for aluminium manganese alloy (92% Al)\textsuperscript{103}. It was indicated that thiourea acts by influencing the cathodic reaction\textsuperscript{105,111}.

Satisfactory protection could be afforded to pure aluminium by a combination of an improved cathodic current of 0.1 amp/sq dm and 1.5 g/liter thiourea\textsuperscript{129}. Thiourea is an excellent inhibitor for aluminium\textsuperscript{41,105,107,116,118,127,128,130}.

Diphenylthiourea is a moderate inhibitor for the corrosion of aluminium-manganese alloy in HCl. It acts by influencing the cathodic reaction\textsuperscript{130}.

Acridine, thiourea and nicotinic acid were studied as inhibitors of corrosion of commercial aluminium (93% Al)\textsuperscript{115}.

(1) SIB-III alloy (90.5% Al), (2) Aircraft zinc alloy (88% Al), (3) Aircraft copper alloy (91% Al), (4) in 1N HCl at 32\textdegree C.

For all the inhibitors, the order of efficiency was 4 > 3 > 1 > 2\textsuperscript{115}. For all the alloys, the order of efficiency was acridine > thiourea > nicotinic acid > dextrin\textsuperscript{129}.

For aircraft aluminium zinc alloy (80% Al) and aircraft aluminium-copper alloy (91% Al) and pure aluminium, the order of efficiency in HCl solutions is acridine > thiourea > nicotinic acid > dextrin\textsuperscript{61, 104}.\textsuperscript{104}
Titova\textsuperscript{66} reported that CUM (found as a byproduct of the oil industry) containing quinoline and pyridine, naphtalene and phenol inhibit the corrosion of aluminium in hydrochloric acid. It is proposed that such organic compounds, approach the charged surfaces of the metal, attract electrons, and combine with the metal through the primary valencies of the nitrogen.

Raather\textsuperscript{141} patented the use of dioxodisiloxane or trialk oxysilanes as inhibitors for the corrosion of aluminium in hydrochloric acid.

Desai and Desai\textsuperscript{143} reported that furfuraldehyde is an excellent inhibitor of the corrosion of aluminium 2S and 3S in hydrochloric acid solutions. It is effective even at very low concentrations. With an increase in the concentration of furfuraldehyde, the efficiency rises up to a particular concentration and then decreases due to the cathodic depolarisation at higher concentrations of aldehyde. It functions by polarising the cathodic areas. The efficiency of furfuraldehyde increases with the increase in acid concentration.

Lichtenberg\textsuperscript{78} reported the use of dibenzyl sulfide, resin and phenol formaldehyde condensation products as inhibitors for corrosion of aluminium in hydrochloric acid and observed that phenol formaldehyde condensation products afford 90% protection to aluminium in 2N hydrochloric acid.
Jabicszynski and Pierzhalski\textsuperscript{139} reported that hydrogen sulfide and carbon disulfide strongly accelerate the corrosion of aluminium in 1.4N hydrochloric acid whereas iodine and thiocyanic acid retard it to an extent of 60% and 47.6% respectively.

Balesin\textsuperscript{143} and Dobychina reported that PB-3, PB-8 and anabasine oxalate are excellent inhibitors for the corrosion of aluminium alloys in hydrochloric acid.

Homer\textsuperscript{78} studied dibenzylsulfoxide, dibenzyl sulfide, triphenylarsinoxyde, benzyl isoquinolinium bromide, tribenzylsulfonium hydrogen sulfate, diphenyl-dibenzyl-phosphonium chloride, diphenylthiophosphonic acid, thiourea, o-tolythiourea, mercapto benzthiazole, allumarin, phenantridine acridine, as inhibitors for the corrosion of aluminium in 1N HCl. Dibenzyl sulfide afford practically complete protection (98%). The performance of dibenzylsulfoxide (92%), triphenylarsin oxide (87%), tribenzylsulfonium hydrazine sulfate (87%) acridine (86%) is satisfactory.

Substituted ethynyl cyclobexyl compounds where the substituent is \(-\text{OH}, \text{OCOCH}_3, \text{OCOCl}, \text{CHO}, \text{Cl}, \text{I}\) or \(-\text{NH}_2\) have been patented as corrosion inhibitors for aluminium in hydrochloric acid\textsuperscript{144}.

\textbf{(e) Sulfuric acid:}

Lichtenberg\textsuperscript{145} observed that chromates reduce the corrosion of aluminium in concentrated sulfuric acid but accelerate the process in dilute sulfuric acid. Benson\textsuperscript{146}, Means also
observed that chromates accelerate the corrosion of aluminium in sulfuric acid solutions. Lichtenberg observed that phenol formaldehyde condensation products protect aluminium in sulfuric acid to an extent of 75%.

Titova studied the inhibition of corrosion of aluminium in sulfuric acid. "CHI", a byproduct of oil industry was found to be the most effective.

Brook reported that hexamine acridine derivatives and quinolive derivatives retard the corrosion of aluminium in sulfuric acid.

Balemin et al. studied the corrosion cracking of aluminium in 0.6N sulfuric acid containing 35 gms/liter sodium chloride. Addition of 0.2% potassium ferrocyanide protects the metal.

Talati and Patel reported the inhibition of the corrosion of 99.8% aluminium and aluminium magnesium alloy (98% Al) by means of sodium arsenite. The inhibitor acts by formation of a protective film. Polarization of local cathodes occurs in presence of sodium arsenite.

Nemcova studied the inhibition of the corrosion of aluminium in sulfuric acid containing sodium and zinc sulfate is inhibited by $\varepsilon$-caprolacton, nicotinic acid, dextrin, quinoline and isoquinoline bases and reported that nicotinic acid afforded protection to an extent of 75%.
(a) Nitric acid:

Eldridge and Mears\(^1\) observed that in nitric acid solutions having acid concentrations lower than 30\%, chromates are effective inhibitors. Colgate\(^101\), reported that nitric acid attack on aluminium can be controlled by chromates, the requisite inhibitor concentration being 0.1\%, up to 10\% acid concentration and 0.5\% for 20\% acid.

Mason\(^151\) et al. report that liquid phase corrosion of aluminium 25-0, 145-T6, 175-T4, 245-T4, 615-T6 and 755-T6 in fuming nitric acid is inhibited by hydrofluoric acid. The corrosion of Al-615-T6 in gas phase of fuming nitric acid is also inhibited by hydrofluoric acid. Subsequently\(^152\) they reported that the protective action of hydrofluoric acid is dependent on the formation of fluoride film.

Ammonium hexafluorophosphate has been suggested as inhibitor for the corrosion of aluminium in fuming nitric acid\(^153\).

(b) Phosphoric acid:

Rohrig\(^154\) and Geir observed that 1\% sodium chromate is an effective inhibitor for corrosion of aluminium in phosphoric acid. Eldridge and Mears\(^1\), however, observed that for the \(\text{H}_3\text{PO}_4\) concentration range 40-60\%, higher than 1\% chromate concentration is needed. Colgate\(^101\) reported that up to 20\% concentration of the acid, 0.5\% chromate is effective.

Eldridge and Mears\(^1\) observed that commercial soluble oils, wetting agents and amines are good inhibitors for the corrosion
of aluminium in phosphoric acid but not as effective as chromates.

Lichtenberg\textsuperscript{147} reported that phenolformaldehyde condensation products effectively retard the corrosion of aluminium in phosphoric acid.

Bach and Rohrig\textsuperscript{135} reported that hexamine is not an effective inhibitor for corrosion of aluminium in phosphoric acid.

\textbf{(f) Organic acids:}

Babe\textsuperscript{153} and Yoshino studied the corrosion of aluminium in sulfamic acid and its inhibition by surface active agents.

\textbf{V. CORROSION INHIBITORS OF ALUMINIUM AND ALUMINIUM BASE ALLOYS IN AMMONICAL MEDIA}

Harvey\textsuperscript{156} patented the use of a mixture of mono and di-ammonium phosphate for the prevention of corrosion of aluminium in 20\% ammonium nitrate solutions and 1\% ammonia. Funkhouse\textsuperscript{158} reported that aqueous solutions containing 11.36\% ammonium dihydrogen phosphate and 10.34\% ammonium nitrate and having 7 or slightly lower pH do not corrode aluminium base alloys if 0.6-1\% fluoride (as NH\textsubscript{4}F or NH\textsubscript{4}HF\textsubscript{2}) has been added.

Stanford and Miller\textsuperscript{159} observed that the corrosion of aluminium and its alloys in 30-30\% NH\textsubscript{4}NO\textsubscript{3} containing 15\% water and 1\% ammonium hydroxide or in a solution containing ammonium nitrate and urea is inhibited by borax, boric acid or organic salts of boric acids.
Wissenberg\textsuperscript{160} patented the use of cupricamine complex

$\left[ \text{Cu} \left( \text{NH}_3 \right)_n \right]^{++}$ (where $n = 2, 4, 5$ or $6$) for the prevention of corrosion of aluminium in aqueous nitrogenous solutions such as ammonium nitrate or urea-ammonia-ammonium nitrate solutions.

Mathiaschits\textsuperscript{161} reports the use of carbonates or sulfates for the retardation of corrosion of an impure aluminium or aluminium alloys in aqueous ammonia. Hydrogensulfide has been suggested as an inhibitor for the corrosion of aluminium caused by ammonia in condensing steam\textsuperscript{25}.

VI. \textsc{Corrosion inhibitors of aluminium and aluminium base alloys in organic chemicals}

(a) Alcohols and Glycols:

For the prevention of corrosion of aluminium in methanol, chlorates\textsuperscript{162}, nitrites\textsuperscript{163} and their mixtures\textsuperscript{162}, amine nitrites have been suggested as inhibitors\textsuperscript{163}.

It has been reported that mixtures of sodium nitrite with sodium tungstate, or sodium selenate or sodium molybdate\textsuperscript{164}, potassium dichromate\textsuperscript{165}, amine nitrites\textsuperscript{163} inhibit the corrosion of aluminium in ethanol. According to Manumott\textsuperscript{166}, carbonates, lactates, acetate and borates prevent the corrosive attack of commercial alcohol on aluminium containers and storage vessels.

The corrosion of aluminium in aqueous alcohol can be prevented
by the addition of a mixture of sodium chromate, sodium benzoate and hexamino (pH 7.5-10) or a mixture of sodium chromate, sodium benzoate and 3 amino-2 methyl-1 propanol (pH 10)⁹.

Phillips¹⁶³ reported amino nitrites as corrosion inhibitors for aluminium in propyl alcohol.

Bayes¹⁶² observed that sodium nitrite, sodium salts of tungstic, salicnic and molybdiric acids prevent the corrosion of aluminium in ethyl alcohol or ethylene glycol.

At pH 7.5-10.5, a mixture of 0.01-2% benzoic acid and 0.1-2% sodium molybdate or arsenate or arsenite protects aluminium from corrosion in methanol or ethylene glycol³⁵.

The corrosion of aluminium in ethylene glycol can be inhibited by the addition of 0.01-1.0% sodium nitrate¹⁶⁷, ¹⁶⁸.

Dempster¹⁶⁹ investigated twentyfive substances as corrosion inhibitors in aqueous glycol and observed that best results are obtained by a mixture of sodium tetrasilicate with borax or sodium cinnamate.

For the prevention of corrosion of cast aluminium in anti-freeze liquids containing glycol, Berger¹⁷⁰ recommended the use of a mixture of sodium arsenite, sodium metaborate, trisopropanol amine borate and sodium mercaptobenzthiazole.
Kelly observed a synergistic action of butyl cellosolve phosphate and diethylamine for prevention of general and pitting corrosion of aluminium in glycol-water mixture.

Langer and Mage reported a synergistic inhibitive action of mercaptobenzthiazole with dilinoleic acid for aluminium in polyoxyalkylene glycols.

Between pH 6-9, a benzoate-nitrite mixture, prevents the corrosion of aluminium in antifreeze mixtures containing glycol. At 1.5% concentration, sodium benzoate, retards the corrosion of aluminium in glycol or glycerol. The inhibitive action of sodium benzoate is enhanced by the addition of 0.1% sodium nitrite. According to Bow, potassium dichromate is not compatible with ethylene glycol systems.

The following substances have been used as inhibitors for the corrosion of aluminium in ethylene glycol: Sodium tungstate, Sodium selenate, Sodium molybdate, amin nitrites, chlorates, nitrates, nitrates, borates, phosphates, sodium benzoate.

(b) Organic bases:
Eldridge and Mears report that sodium metasilicate inhibits the corrosion of aluminium by organic bases such as triethanolamine.

Hervert reported that alkaline metal or alkaline earth
metal salts of alkyl aryl sulfonic acids retard the corrosion of aluminium in organic bases. Sodium dodecyl benzene sulfonate, sodium lignosulfonate, sodium dodecan sulfonate and potassium dodecylbenzene sulfonate are recommended.

Larbre patented the use of amine type inhibitors in presence of citrate or phthalate buffer of pH 4.5-5.5 for the prevention of corrosion of aluminium in polar organic media.

(c) Surface Active agents:
The corrosion of aluminium in aqueous solutions of N-lauryl N, N bis (polyoxyethylene)\beta betaine, N Stearyl N, N bis (carboxymethyl)\beta betaine, or N-N bis 2(hydroxy 3 sulfo propyl) stearylamine, for 40 to 70 hours was investigated by Sato and Kato. At low concentrations of surface active agents (0.05-1.0%) aluminium was completely protected by adjusting pH between 5 and 9. An addition of potassium chromate protected it completely at pH 4 also.

Corrosion of aluminium exposed for 40 to 70 hours to aqueous solutions of sodium alyl phosphate and triethanolamine is completely inhibited by potassium dichromate and chromate respectively.

(d) In Chlorinated Hydrocarbons:
Minford et al. reported that many aluminium alloys are severely corroded by boiling carbon tetrachloride.
corrosion process is inhibited by benzoic chloride, ethyl acetate, ethyl acetoacetate, aluminium nitrate, acetic anhydride phthalic anhydride, acetone, 2, 5 hexanedione, acetophenone, 1, 4 napthaquinone, quinone benzophezone, thiophene, pyrrole, quinoline, cyclohexane, isopropene, triethyl amine, 2 methyl-3 amino-1 propanol methyl amine, diethylamine, trimethylamine, butylamine, 3 methoxypropylamine, cyclohexylamine, 8 hydroxy quinoline, 1, 3, 5, trinitrobenzene.

Boton states that the local corrosion of aluminium caused by hexachloroethane can be decreased by an addition of salts as sodium fluoride, apatite, cryolite, calcium fluoride, potassium chloride and sodium chloride.

Formamide, N Methylformamide and N ethylformamide have been suggested as inhibitors for the corrosion of aluminium magnesium alloys in trichloroethylene and carbontetrachloride176, 185.

Corrosive attack of chlorinated aromatic compounds is inhibited by nitro hydrocarbons182 or by salt of strong acid with weak base183 or by maleic anhydride184.

A small amount of water present in methyl chloride inhibits the corrosion of aluminium1, 10.

The corrosion of aluminium in trichloroethylene is retarded by 0.02-0.05% formamide181. Amines have been suggested as the inhibitors of corrosion of aluminium in bromoform76.
(a) General:

Dillon and Blx suggested chromate type inhibitor to protect aluminium gasoline tanks from the corrosive effect of accumulated sump waters.

Wachter reported that at 0.0001–0.3% concentration, amine nitrite salts inhibit the corrosion of aluminium in gasoline, benzene, kerosene, whereas for the prevention of corrosion of aluminium in acetone, methyl ethyl ketone and methyl vinyl ketone, 0.01 to 0.05% concentration of the inhibitor is required.

Wachter and Stillman reported that the corrosion of metals by small amounts of water in organic materials can be retarded by secondary amines RNHR⁺, where R and R⁺ may be alifatic, alicyclic or heterocyclic radicals.

The addition of N-monocyl derivatives of 9–10 dihydroxy 1–4 diamine anthracene to lubricating greases inhibit the corrosion of aluminium caused by such greases. Alkyl chain of the acyl radical should contain 3–15 carbon atoms if oxidation inhibition is the primary purpose.

Lewry reported that the corrosion of aluminium in commercial red oil, can be reduced by the addition of 'Neram C' (which is an amine or copra fat acids) and other amines of fatty acids.
VII. CORROSION INHIBITORS FOR ALUMINIUM AND ALUMINIUM BASE ALLOYS IN ATMOSPHERE

Canquest\(^1\) patented the use of phenylheptadecylketone and other ketones for protecting aluminium from atmospheric corrosion.

Mantovan\(^1\) reported that naphthalene, formaldehyde, camphor, benzidine, urea, phenyl urea, morpholine, phenyl isothiocyanide and tolyl isothiocyanide act as volatile inhibitors for aluminium in atmospheres containing SO\(_2\).

Paul\(^3\) evaluated several substances as vapour phase inhibitors for aluminium.

Wachter\(^4\) patented the use of nitrites of organic bases such as diisopropylamine, dicyclohexyl amine or dicycloalkylamine as vapour phase inhibitors for aluminium and its alloys. Subsequently\(^5\) he recommended the use of diisopropylamine nitrite, 2 amino butanenitrite and morpholine nitrite as vapour phase inhibitors for aluminium.

Hirate\(^6\) reported that dicyandiamidine nitrite is an effective vapour phase inhibitor for aluminium. Erdos\(^7\) investigated dicyclohexylammonium nitrite as a vapour phase inhibitor and observed that best results are obtained by using the inhibitor in the form of a fatty material, however, in paper and powder form also it is effective. The use of esters of nitrous acids as vapour phase inhibitors has been patented.\(^8\) Esters of alkyl, aryl and heterocyclic nitrites...
have been found to be suitable for the purpose.

Saverina tested pyridine, quinoline, β-picoline and phenol as vapour phase inhibitors for aluminium and observed that these substances do not inhibit the corrosion of aluminium.

Rajagopalan et al. studied m-dinitrobenzene and β-naphthol as vapour phase inhibitors for aluminium.

Rosenfeld et al. observed the effect of the structure and of the inclusion of –OH, –NO₂, –NH₂ groups on the vapour phase inhibitor capacity of (1) aromatic alicyclic and alifatic nitrogen bases, (2) inorganic salts of ammonia, (3) salts of some bases and (4) complex ethers. Strong bases of alifatic and alicyclic compounds ammonium carbonate, Cu(NH₃)₂CO₃ were effective cyclohexylamine, hexamethylenimine, piperidine, morphline and benzylamine were found to be most effective nitrogen bases. Introduction of nitro groups in ortho position increases the effectiveness of benzoates. Aromatic amines and complex ethers were found to be unsuitable.

Shatalov et al. studied monoethanolamine, monoethanol amine carbonate, dicyclohexyl amine nitrite and monoethanol amine benzoate as vapour phase inhibitors for aluminium at various temperatures, but none was found to be effective.

Novashinskaya reported that paper impregnated with dibutyl adipate protects aluminium from corrosion.
The use of amine borate such as cyclohexylamine borate and its homologues such as di, tri, tetra borate for prevention of the atmospheric corrosion of aluminium has been patented\textsuperscript{304}.

VIII. MISCELLANEOUS:

(A) Viscoplastic Substances:

Hagakawa\textsuperscript{205} and Izuyama studied in detail the corrosion of aluminium by viscoplastic substances containing calcium carbonate and its inhibition. They observed that an addition of 0.03% sodium silicate inhibits such corrosion. The addition of NaCl, NaBr or NaI has no influence on the corrosion but fluorides act as accelerators, the order of acceleration of cations of fluorides being Na\textsuperscript{+} > Mg\textsuperscript{2+} > Ca\textsuperscript{2+} > blank > Zn\textsuperscript{2+} > Sn\textsuperscript{2+}. Sodium silicate inhibits the corrosion of aluminium in presence of fluorides also\textsuperscript{206}. Subsequently\textsuperscript{207}, they reported that following conditions are required for substances to function as inhibitors of corrosion of aluminium in viscoplastic substances:

(a) It should have strong colloidal property and be adsorbable on surface of metals,

(b) It must have amorphous structure and large surface area,

(c) It must react with metal surface to form thin film.

(B) Inhibition of Corrosion Cracking:

The corrosion cracking of aluminium alloy V-05 can be effectively retarded by thiourea, pyridine, KI, potassium ferrocyanide\textsuperscript{208}. 
The corrosion cracking of aluminium magnesium alloys can be inhibited by salts of butyric, caproic and benzoic acids.\(^{209}\)

(C) Hydrogen peroxide:
Sodium silicate has been recommended as an inhibitor of the corrosion of aluminium in alkaline hydrogen peroxide.\(^{96}\)
Sodium nitrate, alkali metasilicates and pyrophosphate have also been suggested as inhibitors for the corrosion of aluminium in hydrogen peroxide.

(D) Lead compounds:
Aqueous extracts of lead pigments and soaps are corrosive to aluminium due to their initial high pH and due to galvanic corrosion resulting from lead deposition on aluminium.
Aqueous extracts of lead linoleate, lead ricinoleate and lead laurate inhibit such corrosion due to adsorption of fatty acid anions on the oxide covered aluminium surface.\(^{212}\)

(E) Detergents:
Sodium silicate, as well as phosphate-amine mixtures have been suggested as corrosion inhibitors for aluminium in detergents.
Alkali metal or ammonium salts of alkyl phosphonic acid inhibit the corrosion of aluminium in detergent's solution.

(F) Liquid fertilisers:
Sodium and potassium fluorosilicates inhibit the corrosion of aluminium in liquid fertilisers.\(^{215}\) However, potassium
fluosilicate does not prevent pitting and therefore for the prevention of pitting sodium molybdate should be added to potassium fluosilicate.

(G) Chlorine water and bromine water:
The corrosion of aluminium in chlorine water or bromine water can be prevented by sodium silicate.

(H) General:
Inhibition of corrosion of aluminium alloys by rubber fittings is due to mercapto benzthiazole contained in rubber.

Saturating amino compounds with water increases their efficiency in protecting aluminium.

Fujii reported that Acridines protect aluminium by coating the surface with an active form of resonance product. A lone pair of electrons from the N atom of acridans can be donated to aluminium only when they are free from hydrogen bond association but those of acridines can always be donated to aluminium.

The corrosion of aluminium in single pan cooled handford reactor is inhibited by Na₃PO₄ and NaNO₃ and Na₂Cr₂O₇.

The following substances have also been found to inhibit the corrosion of aluminium:
Maleic anhydride adduct of butyl olate\textsuperscript{221}, octadecanol\textsuperscript{222}, a mixture of octadecylamine and hexadecylamine\textsuperscript{222}, alkanoyl amine alkylcarboxylic acids and its ammonium, alkali, alkaline earth, heavy metal salts\textsuperscript{223} (p-amino methyl) triethoxy silane\textsuperscript{224} emulsions containing mono or diamine, and esters\textsuperscript{225}, carboxycelluloses, alluronic, polyglucosonic, polysalaeturonio, polymannuronio, alginic acids, their ammonium or amine salts\textsuperscript{226}, chromates and permanganates\textsuperscript{227}, a mixture of butylcellose phosphate with ethylamine\textsuperscript{228} reaction products of amines with P\textsubscript{2}O\textsubscript{5} and alkecy alkanol\textsuperscript{229} hydroxyethyl alkyl imidazoline\textsuperscript{230} polyphosphates\textsuperscript{231}. 
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SECTION III

LITERATURE SURVEY OF SUBSTANCES STUDIED
BY US AS CORROSION INHIBITORS FOR OTHER
METALS AND ALLOYS

I. ALCOHOLS

Cyclohexanol has not been reported in literature as corrosion inhibitor so far.

Methyl cyclohexanol retards the corrosion of metals in petroleum residues\(^1\) and has been used as a constituent of antiscorrosion oil\(^2\).

II. ALDEHYDES

Furfuraldehyde prevents the corrosion of zinc anodes in dry cells\(^3\), the corrosion of metal containers and equipment by insecticides and weedicides\(^4\), the corrosion of steel in water\(^5\), and in acids\(^6\), the corrosion of cadmium-antimony alloy in sulphuric acid\(^7\), hydrochloric acid and nitric acid\(^8\).

Takahashi\(^9\) patented its use for the prevention of corrosion of metals by hydrochloric acid, sulphuric acid or phosphoric acid. Desai et. al. reported that furfuraldehyde is an excellent inhibitor for the corrosion of brass in acids\(^10\), and in alkali\(^11\), the corrosion of aluminium in hydrochloric acid\(^12\) as well as for the corrosion of copper in hydrochloric acid\(^13\), sodium hydroxide\(^9\) and potassium persulphate solutions\(^14\). It
has also been used to prevent the corrosion of 63/37 brass in sodium hydroxide and potassium persulphate solutions. Vanilline has been reported as inhibitor of the corrosion of iron, in acidic media by Jenny.

III. KETONES

2-butanone has been used to retard the corrosion of copper and 63/37 brass in potassium persulphate solutions.

2,4-pentanodione has been investigated as an inhibitor of the corrosion of iron, zinc and cadmium in hydrochloric acid, and the corrosion of aluminium, and copper in sodium hydroxide solutions. It has also been used to retard the corrosion of copper and brass in sodium hydroxide and potassium persulphate solutions. 2,5-hexanodione has been used to retard the corrosion of aluminium in chlorinated hydrocarbons by Minford.

Cyclohexanone has been used to retard the corrosion of steel in sulphuric acid at 70-100°C, the corrosion of copper and brass in sodium hydroxide, potassium persulphate solutions, and the corrosion of 63/37 brass in alkali.

IV. Amines:

Geller reported that several aliphatic amines inhibit the corrosion of aluminium in 1.4N hydrochloric acid but the protection afforded is temporary.

Methylamine, dimethylamine and trimethylamine retard the corrosion of iron by canned foods.
Morpholine, cyclohexylamine and ethylenediamine are reported to be suitable inhibitor for steam corrosion.

Mann et al. studied aliphatic and aromatic amines as inhibitors for the corrosion of iron by acids. The salts formed by aromatic amines with corroding acids form blanket-like layers of positive ions adsorbed on the cathodic areas of the metal surface on the Nitrogen atom.

The inhibitor structure determines the closeness of packing of the ions in the covering layer and the character of the film as to its penetrability. Later Mann and Chiao correlated the molecular structure of inhibitors with the efficiency.

Antonucci investigated a number of amines as inhibitors for the corrosion of iron in 1.0N sulphuric acid by loss in weight method. He reported that the inhibitive power depends on the stereochemical properties of the amine, i.e., the area of the metal covered and protected by a single adsorbed molecule. At 0.25% nitrogen, the order of efficiency was found to be trimethylaniline = diethylaniline > triethylamine > methylaniline > ethylaniline > dimethylaniline > dimethylamine > diethylamine > ethylamine < methylamine.

Nathan studied the retardation of the corrosion of iron powder and strips by 1.0N hydrochloric acid by aliphatic and aromatic amines, Viz. methylaniline, ethylaniline,
dimethylaniline, diethylaniline, ethylamine, diethylamine, triethylamine. The effectiveness of amines increases with increase in molecular weight in the homologous series. Steric factors which are more favourable to adsorption of the amine on metal-solution interface increase its inhibitor efficiency.

Diethylaniline, dimethylaniline, ethylamine, diethylamine, were observed as corrosion inhibitors for iron in sulphuric acid by Ride, who reported that the amines are adsorbed in a single and fixed mode of molecular orientation.

Aniline, methylaniline, ethylaniline, dimethylaniline, diethylaniline, methylamine and ethylamine were investigated as corrosion inhibitors for pure iron in 1 CN hydrochloric acid by Kaascho and Hackerman who observed that these substances act as inhibitors by mixed control.

Morpholine and ethylenediamine have been suggested as inhibitors for steel by dimethyl sulfoxide.

Ethylamine, diethylamine, triethylamine, ethylenediamine, methylaniline, were evaluated as corrosion inhibitors for metals in aqueous non acid solutions. The amines which were effective in acidic media were ineffective in non acid solutions. For soluble amines of low molecular weight, high pH was necessary in dilute solutions.

Dimethylaniline, diethylamine and ethylenediamine have been investigated as volatile corrosion inhibitors for steel.
Antropov and Banerjee studied diethylaniline, ethylaniline, ethylamine, diethylnamine, as corrosion inhibitors and calculated the inhibitor coefficients from electrocapillary measurements.\(^{32}\)

Trimethylamine and triethylnamine have been suggested as corrosion inhibitors.\(^{33}\)

Diethylaniline and dimethylamine retard the corrosion of steel by combustion products of sulphur containing fuels.\(^{34}\)

Aniline has been studied as inhibitor for acid corrosion of iron.\(^{35}\)

Zwiersykowska used aniline, diethylaniline to retard the corrosion of zinc and cadmium in 1.0N hydrochloric acid and correlated the inhibitor action with electrocapillary curves.\(^{36,37,38}\)

Dimethylaniline and ethylenediamine have been investigated as corrosion inhibitors by Jenny.\(^{16}\) Diethylaniline and triethylamine have been patented as inhibitors for the corrosion of oil well casing and tubing.\(^{39}\) Dimethylaniline has been used to prevent corrosion of steel equipment during rectification of hydrocarbons.\(^{40}\) Diethylaniline has been investigated as an inhibitor for corrosion of lead and tin in nitric acid, as an inhibitor of corrosion of automobile engines and to protect equipment of oil wells.\(^{42}\)
Ethylenediamine has also been used as a vapourphase inhibitor. Cyclohexylamine is used to retard the corrosion of condensers and boiler corrosion as volatile inhibitor. It also prevents the corrosion of carbon steel in carbon tetrachloride.

Morpholine retards the corrosion of metals in sulphurous media, the corrosion of condensers and boiler corrosion as inhibitor for the corrosion of copper in petroleum as vapourphase inhibitor.

Hexamine has been extensively investigated as an inhibitor of metallic corrosion. It retards the corrosion of aluminium in acid solutions, but not in alkaline or ammonical solutions.

It protects metals such as iron, copper, aluminium and solder metal in water or alcohol, alone or in combination with sodium chromate or sodium benzoate. It does not retard the corrosion of copper in acids.

The corrosion of manganese in manganese chloride is retarded by hexamine to an extent of 60%.

Hexamine prevents the corrosion of titanium in hydrochloric acid, and in sulphuric acid.

Hexamine has been investigated as an inhibitor for the corrosion of indium, tin and indium-tin alloys in 20% sulphuric acid and in 5% hydrochloric acid.
Numerous investigations on the retardation of the corrosion of steel by hexamine in diverse aggressive media have been carried out. It has been observed that as a vapour-phase inhibitor, hexamine protects steel but not copper or copper alloys. It protects steel from corrosion cracking in 42% magnesium chloride. Hexamine has been reported as an inhibitor for the corrosion of steel in acids in sulphuric acid, in hydrochloric acid, in nitric acid, in mixture of sulphuric acid and nitric acids at various pH. For the prevention of corrosion of steel in HCl or H₂SO₄, the effect of KI, KBr or SnCl₂ in conjunction with hexamine was studied. A synergistic protective action of hexamine with acridine +KBr, PB - 5, AS₂O₃ + Urea, thiourea, KI has been observed for steel in acids.

It is also used as a pickling inhibitor and as a volatile corrosion inhibitor.

Aniline has been used to retard the corrosion of iron in acids, the corrosion of copper in benzene, in sulphuric acid, the corrosion of copper, iron and nickel in acids, the corrosion of copper and brass in nitric acid, as a vapour-phase inhibitor. Its adsorption on mercury has also been studied. o-anisidine has been studied as an inhibitor for the corrosion of copper and brass in nitric acid. Dimethylaniline has been patented as corrosion inhibitor, diethylaniline retards the acid corrosion of steel.
The use of a mixture of sodium alginate and sodium silicate has been patented for protection of metallic surfaces from corrosion.
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