Choice of Corrosion Resisting Materials in Extraction of Metals

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For recovery of different metals from metallic ores, chemical and pyro-metallurgical treatments, such as roasting, smelting and leaching are performed under varying conditions of temperatures, pressures and corroding media. Since the economics of a process is influenced among others by the life of the equipment, materials for construction thereof are selected so as to possess required resistance to corrosion and abrasion. This paper reviews the use of various metals and alloys possessing maximum corrosion resistance for extraction of metals under certain specified conditions.

METALLURGICAL practice for the extraction of metals can be divided mainly into the following steps :—

1. Concentration of ore.
2. Roasting of the ores or concentrate in cases of sulphides and arsenides.
3. (a) Smelting the ores or roasted concentrates to crude metals or metals in case of pyrometallurgy. (b) Leaching with acids or alkalies for selective solution of the required metal in pyrometallurgical processes. The leached solutions are further purified for the production by electrolysis of pure metal or pure compounds, which are treated to reduce them to metallic state.
4. Purification of crude metal by electrolysis or pyrometallurgical processes.

Thus for the recovery of metal from the ores, various steps are to be performed under different conditions of temperature, pressure and corroding media. The proper selection of materials for the construction of equipment in a plant is directly dependent on (i) the mechanical properties at working temperature e.g. strength, creep, ductility etc; (ii) resistance to corrosion by the gases, acids, alkalies, liquid metal etc. at different working temperatures and pressure; (iii) overall economy.

Various metals and alloys have been developed to withstand deterioration under different conditions but the use of costly materials, such as high alloy steel for fabrication of equipment is decided by the overall economy.

ROASTING

Sulphide and arsenide ores are commonly roasted either completely to get an oxide or are partially

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roasted to attain a specified metal to sulpher ratio or to convert sulphides into sulphates. Roasting is generally carried out in multiple-reverberatory roaster and Dwight Lloyd type of furnaces. During roasting the gas is laden with sulphur and sulphur compounds e.g. SO_2 and SO_3, oxygen, water vapour with some arsenic and arsenic compounds. High temperature chemical corrosion is however the important factor to be taken into account for the selection of material of construction.

In multiple reverberatory type of furnaces cast iron and steel rabble arms and rabble blades are generally used in industries. Due to deterioration in strength at high temperature, corrosion and growth (in case of cast iron) the life of such parts is not high (250-400 days)[1]. In addition, changing of arms and blades requires shutting down, which affect the efficiency and economy of the operation. Under conditions prevailing in the roasting furnaces the presence of sulphur compounds has got greater effect on the corrosion of materials. As such, melting points of sulphides or any other system with sulphides formed after the reaction of the elements in the material with sulphur will affect the corrosion rate. According to Vogel and Reunbach[2] because of Fe-Cr-FeS system having a high melting point, chromium steels show greater resistance to corrosion in presence of SO_2, H_2O etc. So for rabble arms and blades steel containing 22-25% chromium and 1-1.25% carbon gives excellent performance[1]. Resistance to corrosion and abrasion increases with increase in chromium and carbon content and as such chromium and carbon are kept high as shown in Table 1[3]. In cases of ores where abrasion is more rapid than high temperature corrosion, 3% Cr white iron is used which is extremely hard. Fig. 1 gives the conditions of ordinary cast iron and alloy cast iron rabble after use[4].

When chromium-nickel austenitic stainless steel

TABLE I

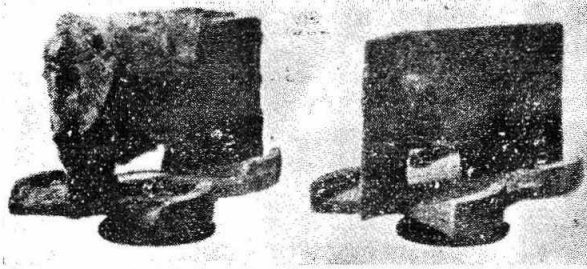| Composition %			Inch Penetration	Per Year
			24 hrs.	96 hrs.
C	Cr	Ni	1050°C	900°C
1.5-3	25-30	—	4.7—8.8	1.1—1.5
1	22	25	11	4.3
0.9	17	34	14	3.3
0.67	19	40	8.8	4.0

FIG. 1

is used, it has been found that severe pitting occurs in many cases. This deteriorating effect of nickel is attributed to the formation of nickel sulphide or mixture of nickle sulphide and nickel oxide[5,6] which has low melting point. Here mention may be made of chromium-manganese austenetic steel which show better resistance to corrosion than Cr-Ni steels against high temperature attack by gases containing sulphur compound as shown in Table II[7].

TABLE II

[A 17.90 Cr , 9.04 % Ni 0.40% Mn, 0.10 % C ;
B 17.73 % Cr, — 8.63% Mn, 0.86 % Cu, 0.08%C]

Corrosive gases	Condition of test.	Duration of test hours.	A % loss in wt.	B % loss in wt.
SO₂	400°C	1500	0.04	0.13
,,	550°C	750	0.38	0.10
,,	900-950°C	66	1.51	0.47
			(pitted)	(no pitting)
H₂S	550°C	750	4.0	2,70
,,	850°C	66	converted to sulphide.	converted to sulphide

As the strength and creep resistance properties of the Cr-Mn steel in comparison to Cr-Ni steel at high temperature are low these can only be used at comparatively lower temperature. For handling hot calcines, austenitic chromium nickel or chromium manganese steels can be used as linings for bins, hoppers and passage from bins to smelting furnace.

One important factor is the effect of solid particles deposited on the surfaces of heat resisting steels.

In sulphurous atmosphere, attack on the underlying metal is accelerated if the particles are sulphides and can absorb sulphur e.g. lime, magnesia-alumina etc[8]. Greenwood & Roennfeldt[3] found that pitting of zinc roasting rabbles and rabble arms increased with increase in galena content of the ore. This is probably due to the fact that melting point of galena is quite low and so it sticks to the rabble arms and blade more easily.

PYROMETALLURGICAL EXTRACTION AND REFINING

For smelting of ores, blast furnaces and reverberatory furnaces are used. In reverberatory furnaces the heating fuel used is coke, gas or oil. When the fuels are burnt completely in air the resultant product of combustion contains, in addition to CO_2, H_2O etc., some SO_2, the amount of which varies according to the sulphur content of the fuel. Above 0.01%, SO_2 in the product of conbustion increases the rate of oxidation of steel, the increase depending on the amount of SO_2, temperature and type of steel[x]. The grate bars for firing coke is commonly made of nickel-chromium cast iron or chromium white iron as these have high resistance to oxidation and abrasion. In case of oil or gas fired furnaces the burners project inside the furnace. The temperature in the immediate vicinity of the burner is considerably lower than the hottest zone of the furnace even then the temperature is sufficiently high for commonly used heat resisting alloys. The use of high chromium alloy (25-28% Cr) steels or high chromium-nickel (25-28% Cr and 1-10% Ni) steels are used for the construction of burners[x]. High chromium alloy burners have been successfully used for a period of 7000-10000 hours[9,4]. As chromium or chromium-nickel steels have excellent resistance to corrosion by water, the water side corrosion does not present a great problem. In the case of high sulphur fuel chromium-nickel alloy should not be used.

Retorts used for the reduction of MgO in Pidgeon process, reduction of $TiCl_4$ by Mg in Krolls process etc. should have both good resistance to oxidation and good mechanical strength at the operating temperature. High chromium steels are suitable for these purposes and 35% chromium and 15% nickel gives good result[9].

Use of cast iron pots for melting and handling of metals is extensively made in industry. Cast iron usually fails at high temperature service due to scaling, growth and creep. Various additions are made to cast iron to increase the heat resisting properties. Addition of 7-9% of silicon to cast iron imparts excellent resistance to scaling, growth and deflection up to about 850°C and so can be used for melting non-ferrous metals and alloys having low melting point. Up to 850°C, 1-2½% chromium and 1-3% Ni cast iron can also be used[10]. If grey cast

iron is used it should have as fine a structure as possible.

FLUE DUST, FUME AND GAS RECOVERY

For handling gases produced from roasting and smelting furnaces ordinary steel is not used for the construction of flues, scrubber etc. The use of concrete and steel pipes lined with bricks or asbestos are made but they have many constructional disadvantages. The use of heat resistant steels for the construction of flues can be made for carrying hot sulphurous gas but their use is limited from the standpoint of cost involved.

The gas from the roasting or smelting furnaces is first cleaned in scrubbers. In cases of gas laden with sulphur dioxide the scrubbers are lined with lead and the circulation of water through the scrubbers is done by means of corrosion resistant pumps and pipes. The circulating water dissolves sulphur dioxide to form sulphurous acid. The sulphurous acid may be partly oxidised to sulphuric acid in the presence of dissolved oxygen. Lead lined pumps and lead or lead lined tubes can be used if the temperature is not very high. In presence of sulphuric acid, sulphurous acid attacks austenetic stainless steel and pitting is likely to be produced, specially at high temperature. This attack can be reduced to a great extent by the addition of molybdenum upto about $3\frac{1}{2}\%$ to Cr-Ni steels[8]. Worthite (20% Cr, 24% Ni, 3% Mo, 3.25% Si, Cu, Mn, 0.07% C, balance Fe) pumps have also been successfully used for circulation of water over the scrubbers[11]. For spray nozzles in scrubber towers or fans for handling gas containing sulphur dioxide Durimet T (22% Ni, 19% Cr, 3% Mo, 1% Cu, 1% Si, 0.07% C) can be used[12].

For final purification of gases electrical precipitators are used. As in most cases the precipitation is carried out at low temperature, oxidation problem is not involved in the construction of precipitators. No steel products, alloys or otherwise, have been found to show high resistance to corrosion under the conditions prevailing in the precipitator. For this reason lead plates or purest aluminium are used[1]. For high temperature cleaning in Cottrell precipitator the emmission electrodes and earthplate frames are made of 18% chromium steel[13].

LIQUID METAL CORROSION

Melting pots and handling ladles are generally lined with refractory bricks to avoid contamination of the molten metal. But the use of unlined equipment is more economical if suitable resistant material is found. In addition to these many equipment are exposed directly to liquid metal and are attacked by the liquid metal as follows:—

    (a) Direct alloying
    (b) Solution attack
    (c) Intergranular penetration

Corrosion as has been found in handling liquid magnesium and some other metals will be discussed next.

MAGNESIUM

Pots and ladles for melting magnesium are generally made of cast iron and low carbon steel. Steel is preferred to cast iron as cast iron is quite porous and so cannot hold the slag; specially the heating and cooling makes cast iron more porous due to the growth[14]. The iron pickup by magnesium is quite high at the working temperature because cast iron and steel possess good resistance to attack by magnesium at 650°C and limited resistance at 800°C[15]. Pumps and pipes made of cast iron and steel have ben successfully used to transfer the molten magnesium to ingot casting machine or for stirring of molten magnesium in the melting bath.[16] High chromium steel is desirable as far as its heat resisting qualities are concerned but its resistance to corrosion by molten metal is not better than cast iron or low carbon steel.[15] Steels containing nickel or cobalt as major alloying elements are not suitable for handling molten magnesium as they are highly soluble in magnesium.[17]

ALUMINIUM

There are no known metals and alloys which are immune to attack by molten aluminium. Metal equipment if coated with inert metallic oxide e.g. Al_2O_3, MgO etc. by painting or spraying and thoroughly dried before use give excellent resistance to attack by aluminium. However, in industrial practice, cast iron crucibles are being successfully used for melting aluminium. Chromium has good resistance to attack by aluminium at temperatures near its melting point. The use of chromium plated ingot moulds may find wide use in the construction of ingot moulds.

Copper, nickel and alloys containing one or both of them as important constituent namely monel, inconal brasses etc. are severely attacked at all temperatures. Graphite has high resistance to corrosion by aluminium and the resistance of grey cast iron is attributed to the graphite barrier left behind when iron is dissolved.

ZINC AND LEAD

Zinc attacks most of the metals and alloys severely at 500°C. Graphite or metals coated with graphite or chromium can be used for handling molten zinc. Lead can be handled easily in steel containing up to 0.5% carbon, cast iron, low chromium steels and high chromium steel[15] up to 600°C, but they have poor resistance at 1000°C. For pumping molten lead steel pumps and pipes have been successfully used.

CORROSION TO VARIOUS ACIDS

Use of acids chiefly sulphuric and hydrochloric are largely made in hydrometallurgical processes for

leaching of ores. Such processes involve handling and transporting of large volume of acid and acid solutions, the efficiency of which largely influences the economy of the process. The corrosion of materials used for handling acids and salts in the leached solutions is affected by many factors e.g. type of acid and salt, concentration, temperature pressure of reaction, rate of flow, oxygen concentration etc. As hydrochloric and sulphuric acids are hydrogen discharging type of acids, all metals except noble metals like gold, silver etc. are attacked. Among the intermediate and base metals the resistance of a metal to corrosion increases if it has a high hydrogen over-potential or if the product of corrosion is insoluble and forms an adherent non-porous layer on the base. Thus the metals and alloys like lead, Durichlor etc. resists the corrosion of acids because the product of corrosion is insoluble in that acids while corrosion resistance of nickel, monel metal etc. in acid is attributed to the high hydrogen over-potential of nickel.

SULPHURIC ACID

For handling sulphuric acid and the acid sulphate leached solution lead is extensively used. Lead is generally given as a lining to wooden, concrete or steel tanks, pipes, valves, pump impeller etc. Pure
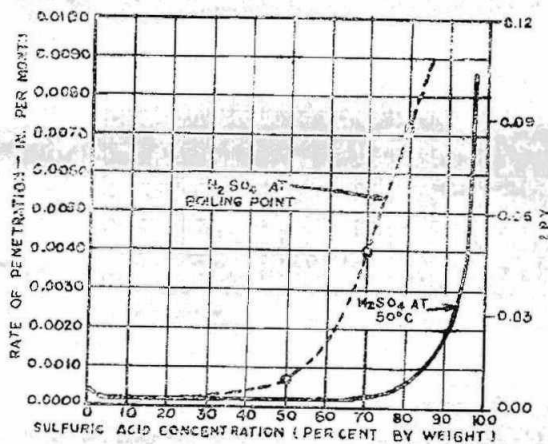
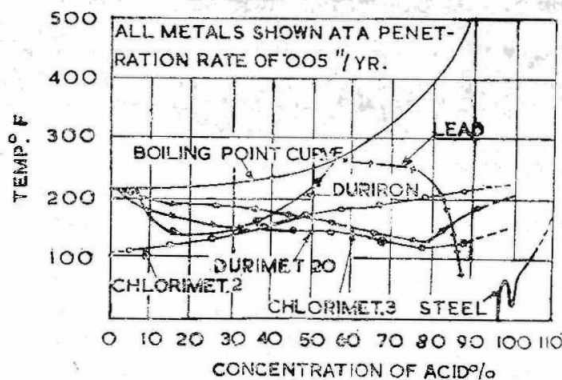FIG. 2—Corrosion of lead in sulphuric acid.

FIG. 3—Metal corrosion by sulphuric acid [Penetration rate 0.005 in./yr.]

lead has poor mechanical properties, especially it is easily fractured at bends where vibrational stresses are produced. That is why lead is used in an alloyed form and not as a pure metal.

The high resistance of lead in sulphuric acid is due to the formation of an adherent nonporous layer of lead sulphate on the surface. The resistance to corrosion of lead in sulphuric acid of different strength is given in Figs 2[12] and 3[19], from which it is seen that sulphuric acid can be handled in lead upto concentration of 80% at 50°C and 50% at boiling point without much loss. High velocities also increase the rate of corrosion as shown in Table III[34] though rates appear to fall with initial increase of velocity..

Velocity of solution across lead surface		Rate of corrosion	
meters/min	lt./min	i.p.y.	inch/month
2.6	8.4	0.0066	0.00055
30	97	0.0020	0.00017
47	155	0.0019	0.00016
92	300	0.0103	0.00086

Antimonal lead (up to 8%) is most commonly used and its resistance to corrosion does not vary much from that of tellurium lead up to 95-120°C. But above this temperature tellurium lead (0.035% – 0.05% tellurium) give better performance up to 230°C.

High silicon iron is largely used for making pumps and valves for handling sulphuric acid, acid sulphate leached solution or sludge. High silicon increases the resistance to corrosion of iron due to the highly non-reduceable silica film formed on the surface and so the rate of corrosion does not depend on the oxidising. reducing or neutral conditions. As seen from Fig. 4[21], 14-15% silicon in iron results in maximum corrosion resistance, and so no significant benefit is derived by increasing the silicon beyond this amount. These alloys being very hard and brittle cannot be worked or machined and so are cast to proper size and then ground by special machines to finish.

Durimet 20(Ni-29%, Cr-20%, Mo-12% min. Cu-3% min. Si-1%, C-0.07 maxm. Fe-Balance) can also be used for sulphuric acid or acid sulphate leached solution. In this austenetic steel, copper and nickel provide good resistance to sulphuric acid, chromium provides good resistance under oxidising conditions and molybdenum increases resistance to acid and pitting.[22] From Fig. 3[19] it is clear that unlike lead it can be used over the entire concentration range upto 65°C.

Chlorimet 2 and 3 (63% Ni. 32% Mo. 3% Fe maxm. & 0.010 C and 60% Ni, 18% Cr, 18% Mo, 3% Fe, 1% Si and 0.07%C respectively) show excellent resistance to corrosion in sulphuric acid of
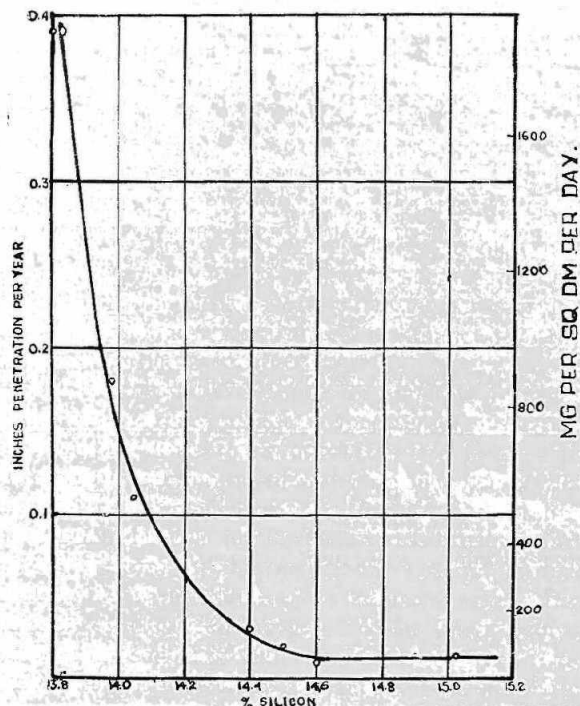
FIG. 4—*Effect of alloyed silicon on corrosion resistance of iron in 10% H_2SO_4 at 80°C (175°F)*
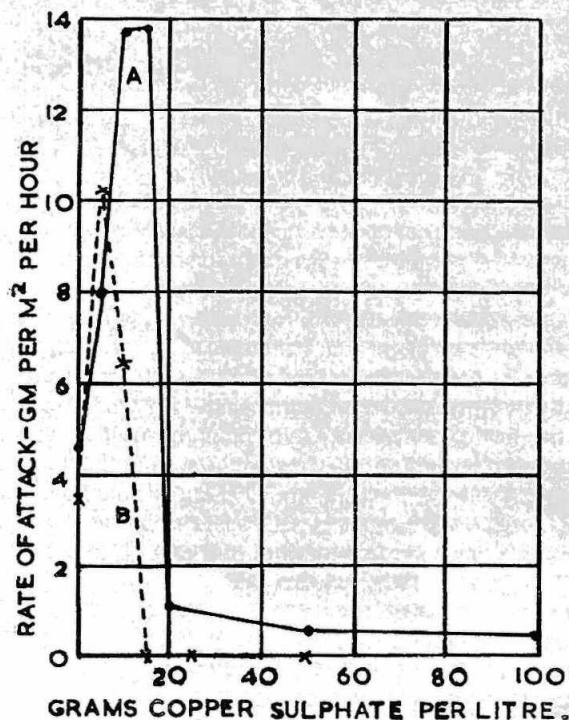

FIG. 5—*Effect of copper sulphate on the rate of attack of dilute sulphuric acid on 12-14 per cent chromium steel at 15°-20°C [Curve A— solutions containing 100 grams free sulphuric acid per litre; Curve B—solutions containing 50 grams free sulphuric acid per litre.]*

the concentration from 0-100% up to 50°C and good resistance up to 90°C except for the dip portion as shown in Fig. 3[19] . It can be used for pumps, valves, agitators etc. where lead fails due to erosion and corrosion. As it is relatively expensive its application is limited to severely corrosive condition. Hastelloy A & C can also be used to handle sulphuric acid but not under all conditions of temperature and concentration.

In all the stainless steels containing chromium above 12-14% presence of copper or ferric sulphate in acid solution inhibits corrosion, the degree of inhibition depending on the amount of sulphates, free acid, temperatures and composition. As shown in Fig. 5[23] the passivation increases with increasing chromium content of the steel. Presence of nickel further reduces the minimum amount of sulphates required to inhibit the corrosion while with rise in temperature. amount of sulphates required is reduced as shown in Table IV[23].

TABLE IV

Strength of Solution (gms per litre)		Rate of Attack (Gm/Sqm/hr) at				
Sulphuric Acid.	Copper Sulphate	20°C	40°C	60°C	80°C	Boiling
100	nil	0.95	1.80	9.7	45.6	83.2
,,	0.05	2.07	3.11	13.4	...	...
,,	0.10	nil	nil	15.1	...	...
,,	0.15	...	...	11.5	85.0	...
,.	0.20	nil	nil	nil	49.1	...
,,	0.25	nil	nil	nil	nil	245
,,	0.40	...	...	..	...	232
,,	0.50	nil	nil	nil	nil	nil

As these sulphates are of oxidising types, if not present above certain critical amount they show signs of pitting and thus accelerate the corrosion. The presence of these salts in acid solution increase the corrosion rate of stainless steels containing no chromium. Non-oxidising sulphates of zinc, nickel etc. in acid solution have no effect on the corrosion rate which depends on the amount of free acid present and the acidity of these salts in solution.

HYDROCHLORIC ACID

Hydrochloric acid is a highly reactive acid and so special materials are required to handle this acid. Nickel and monel metals possess quite good resistance to corrosion by hydrochloric acid specially at low concentration, temperature and under non-oxidising conditions. Addition of molybdenum to nickel produces alloy showing high resistance to corrosion by hydrochloric acid as shown in Fig. 6[24]. On this basis various alloys have been developed containing different amounts of nickel and molybdenum namely Hastelloys, Chlorimets and Coronel etc. Of these alloys Hastelloys A & C
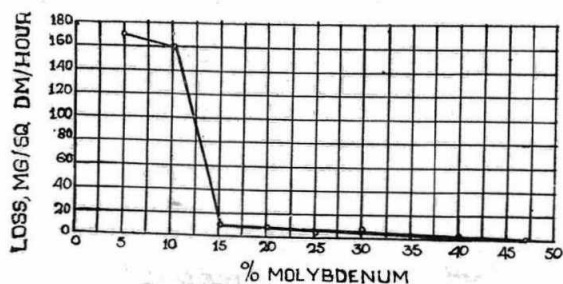
FIG. 6—*Corrosion of Ni-Mo alloys in 10% HCl at 70°C (158°F)*

are very important and largely used. Type A (Nil 55-60%, Mo 18-22%, Fe 18-22%) is highly resistant to corrosion at high acid concentration in the absence of oxidising agents. Presence of chromium in Type C (Ni—54-66%, Mo—15-19%, Cr—13-16%, Fe—4-7%) alloy increases the resistance to corrosion in presence of oxidising agents. Thus the acid solution containing oxidising salts e.g. ferric chloride and cupric chloride can be handled in Hastelloy C but not in Hastelloy A.

High silicon iron of Duriron type containing 3-4% of molybdenum (Durichlor) shows high resistance to corrosion in hydrochloric acid under both oxidising and non-oxidising conditions as shown in Fig. 7[25]. The increase in temperature reduces the
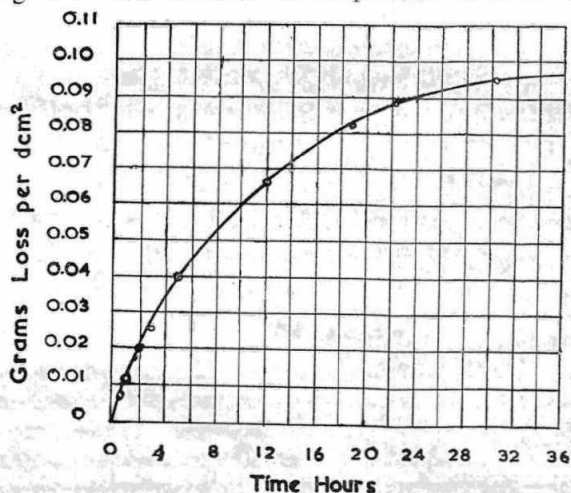

FIG. 7—*Behaviour of durichloride in concentrated hydrochloric acid*

time for flattening the curve while decrease in concentration increases the time for the same. Prolonged immersion of this alloy in hydrochloric acid shows a grey coloured surface film. If this film is removed corrosion rate again increases, showing that the resistance to corrosion is due to the presence of protective surface film.

ALKALIES

Resistance of iron and steel to alkalies is quite

good at low concentration and temperature, but with increase in concentration and temperature it becomes necessary to add nickel to iron and steel. Thus high nickel cast-iron, austenitic stainless steel, Cu-Ni alloys, Ni etc. have high resistance to corrosion at high temperature. These costly alloys can be replaced by other less resistant metals and alloys, by iron and steel, low chromium or nickel steel provided the contamination of the solution does not affect the product or this can be used before the final purification of the leached solution.

To replace metallic part for handling chemicals by chemically inert non-metals such as plastic, stone wares, glass etc. is the growing interest of the engineers. The use of materials other than plastic is not new in chemical process industry. The use of rubber lined tanks and pipes for storing and transferring of dilute acids or alkalies is of standard practice. the use becomes limited with increase in concentration and temperature. Rubber diaphgram pump is used for handling of slimes where both corrosion and abrasion are important. Glass and porcelain are almost chemically inert but their use in industry is not widely practiced. In some cases glass lined steel tanks or porcelain vats are used for storing highly corrosive chemicals. Graphite is also inert to almost all non-oxidising chemicals.

The use of plastic, primarily for its resistance to corrosion, light weight and easy formability is drawing more attention of the engineers. A good number of plastics are available now-a-days and selection of materials for manufacturing plastic equipment depends on their specific use. Certain plastics may be used even at a higher temperature upto 130°C. Polyvenyl chloride[25] is an excellent chemical resistant and high strength plastic and may be used for suitable substitute for copper and steel. Polyvinyl chloride[26] is resistant to nitric acid, chromic acid and to most corrosive salts and alkalies upto 65°C and may be used as lining for steel and wooden tanks for handling such chemicals. Compounded saran rubber[25] is resistant to H_2SO_4, HCl, many salts and some alkalies at temperatures upto 65°C. Polyethylene, Polyvinyldene chloride, high impact rubber resin blends[26] are used as plastic tubes for carrying acid, caustic alkali and electroplating solutions.

The masonary construction of the plant where leaching, electrolysis etc. are carried out should be sufficiently resistant to chemicals involved in the processes. Generally the prime concrete slab in floors are covered with an impervious membrane which in turn is protected by acid or alkali resistant bricks or tiles. These are joined by chemical resistant cement e.g. plasticized sulphur cement, furane cement, modified phenolic cement[26] etc. Plasticized sulphur cement is only used where alkalies and oxidising acids are not handled while furane cement can be safely used for proper floor construction of

the plant where alkalies and oxidising acids are used.

INSOLUBLE ANODES

In the electrolytic extraction and some times in refining of metals, the anodes used should be insoluble in the electrolyte. Many of the metallic insoluble anodes used in the extraction of metals are relatively soluble in the electrolyte without applied current but becomes almost completely insoluble when serving as an anode. This has been explained by C. G. Fink[27] due to the infinitely greater reaction at anode of the equation (2) over equation (1) given below.

$$SO_4 + Me \quad \text{----} \quad 2M^+ + O + 2e \quad ......(1)$$
$$H_2O \text{--} H + OH \text{---} 2H^+ + O + 2e \quad ......(2)$$
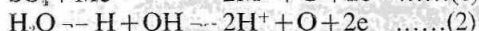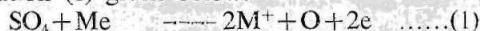
So higher the rate of evolution of oxygen, the more insoluble will be the anode because the oxygen forms a strongly protective oxide layer. It has been found that the combination of metal oxides on the surface is more effective and efficient than one or the other oxide only. Table V[23] gives the different insoluble anodes used in different electrolytes and the type of oxide layers they form. Lead with other alloying elements e.g. antimony, silver etc. is largely used as anodes in electrolytes containing sulphuric acid. In the production of electrolytic manganese lead-tin, antimony, cobalt alloy is used because with it practically all the manganese is deposited at the cathode while with lead and lead-antimony anodes about half the manganese is deposited on the anode as MnO_2 and other half at cathode as metal.[28] In the electro-deposition of zinc, lead-silver instead of lead-antimony anodes are used because the antimony dissolving in the solution seriously interferes with the electrolysis.

TABLE V

Composition	Surface Film	Remarks
Magnetite	Fe_2O_3	Limited use in Europe.
Lead + 4%-12% Sb.	$PbO_2 + Sb_2O_3$	For electrolytic copper refineries.
Duriron (11% Si)	$Fe_2O_3 + SiO_2$	,,
Copper silicide	PbO_2, MnO_2 SnO_2	Used by Chile Copper Co. for silver free copper.
Lead + Silicide	$PbO_2 + A_2O (+ S_2O_5)$	Used in electrolytic zinc plant.
Lead − Sn-Sb-Co	PbO_2, SnO_2 Sb_2O_3, CO_2O_3	For the production of electrolytic manganese.

For the electrolysis of fused salt graphite or carbon anodes are generally used.

CHLORINE AND IODINE

The choice of materials resistant to chlorine gaseous or liquid dry or wet is a great problem for the purification and extraction of metals by chlorination process. Dry gaseous chlorine at room temperature is inert to most of the metals, but the dry gas when heated attacks all metals to a certain extent. In the presence of moisture, the attack extends to the maximum due to formation of HCl and HOCl which attacks readily most of the metals except certain noble metals such as platinum, tantalum, silver etc. Platinum and tantalum are resistant to chlorine both wet and dry but their use is somewhat limited because of their high initial cost. High silicon[29] alloys containing 14.5% Si, with and without 3% Mo shows excellent resistance to chlorine (wet and dry), the use of this alloy is limited for its extreme hardness and non-workability. Hastelloy C[29] has been successfully and extensively used for handling chlorine in such equipment as valves, pipings, vessels, and feed pipes. For handling nearly dry chlorine gas Hastelloy C has been reported to offer good resistance even at a temperature upto 982°C. At room temperature high Ni-Cr alloys such as Chlorimet 3[29] for handling wet and dry chlorine and "Durimet T" and "Durimet 20" for handling dry chlorine have been reported for satisfactory service. Nickel, monel and inconel are resistant to gaseous chlorine when dry even at high temperature, but it suffers attack from wet chlorine. Lead[29] is recommended for handling dry and wet chlorine, gaseous or liquid safely with a tolerance of slight attack upto 110°C. The use of graphite[29] tube for the introduction of chlorine to molten metallic bath is of standard practice. The graphite or carbon is inert to wet and dry chlorine upto 1649°C, provided no strong oxident at the specific temperature is present. The use of glass lined steel tanks for the storage of dry or wet chlorine gas or chlorine water is limited to the working temperature and can be used upto 93° − 149°C. The rubber lined tanks, pipes, valves etc. are reported to be of satisfactory service for handling dry chlorine gas. Some silicone greases such as D.C. plug cock type and siliastic 120 and 125[29] containing silicones materials in various forms can be effectively used in valves for handling low pressure chlorine at atmospheric temperature.

The results in Table VI (see page 309) of tests carried out on different samples of pure metals and alloys exposed to atmosphere of iodine at a pressure of 400 mm and temperatures of 300-450°C show that for practical purposes Hastelloy B is most suitable for the construction of deposition vessel in Van Arkel-de Boer iodide process for purification of Zr, Ti etc. For some internal parts, subjected to severe corrosive conditions e.g., electrode tip, screen etc., molybdenum is largely used. Platinum

plants. Among those who have specialized in the design and manufacture of these plants, mention may be made of Elkem of Norway, Lectro-Melt, Birlec, G.W.B.—Leone Tagliaferri, Brown Boveri, Siemans, Demag.

CHOICE OF CORROSION RESISTING MATERIALS . . . . . .

TABLE VI

Material	Penetration Rate, 10⁻⁶ cm/day at	
	300°C	450°C
Platinum	0	1.5
Gold	0	6.5
Molybdenum	0.9	9.0
Tantalum	1.2	241
Hastelloy B	12.1	127
Hastelloy C	15.5	—
Inconel	29.2	148
Nickel	75.2	332
310 Stainless Steel	—	487
304 Stainless Steel	—	868

and gold give excellent corrosion resistance at high temperature though they are attacked at lower temperatures. This is thought to be due to the instability of iodides at high temperature. For this reason gold can be successfully used as gasketing material.

CONCLUSION

In conclusion it may be mentioned that more attention is needed on the use of corrosion resisting

materials in the extraction of metals and alloys. Closer co-operation between industries and the metallurgists will be required as the application of various corrosion resisting metals and alloys can only be decided after extensive field and laboratory tests.

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