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METALLIC LEAD PRODUCTS DIVISION

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To Members of the Metallic Lead Products Division:

Attached is a copy of a paper prepared by the Association and presented at the 1949 Conference of the National Association of Corrosion Engineers, Cincinnati, Ohio, April 11-14.

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Secretary

Physical and Corrosion Characteristics of Lead in the Chemical Industry

By

KEMPTON H. ROLL
Lead Industries Association

A Paper Presented at the Fifth Annual Conference, National Association of Corrosion Engineers, Cincinnati, Ohio, April 11-14, 1949

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Physical and Corrosion Characteristics of Lead in the Chemical Industry*

By KEMPTON H. ROLL

A STUDY OF the corrosion characteristics of lead without including its physical characteristics as well would represent only a partial consideration of the role of lead in the chemical industry. From information in the files of the Lead Industries Association, and through the cooperation of its members who represent both producers and consumers of lead, this paper has been prepared in an effort to evaluate the performance of lead and the service it renders to the chemical industry in terms of its physical and its corrosion characteristics. It is important to the lead industry as well as the chemical industry that users and potential users of lead be fully aware of what they can and cannot expect from it.

ABOUT THE AUTHOR—Kempton H. Roll, presently a member [illegible] with the Lead Industries Association, began his [illegible] at Carnegie Institute of Technology, then [illegible] to Yale where he received his bachelor's degree. After service in the navy he was employed by a [illegible] manufacturer as [illegible] research engineer. He currently is studying for his master's degree at Polytechnic Institute, Brooklyn.

Chemical Properties

The broad use of lead as a material for keeping corrosive chemicals under control is natural, since it successfully repels the attack of so many corrosive chemicals. The protection afforded by lead is achieved in most instances by the formation of a thin adherent surface film of oxides or salts which form when the lead is exposed to corrosives. It is this film, serving as a protection to the metal beneath, which gives lead its corrosion resistance.

Lead generally has good resistance to neutral solutions where lead carbonate and possibly oxide are corrosion products, and fair resistance to alkaline solutions in which these are soluble. Experience has shown that lead is commercially resistant to chromic, sulfuric, sulfurous and phosphoric acids; that it is subject to corrosion at somewhat higher rates by hydrochloric and hydrofluoric acids; and that it is susceptible to being strongly corroded by acetic, formic and nitric acids. Also, nitrate salt solutions are moderately corrosive whereas carbonate solutions are not.[1]

Corrosion Rate Interpretation

It is important in discussing corrosion that a uniform system of designation be used, such as inches penetration per month or year or milligrams per square decimeter per day. But either of these systems can be somewhat misleading in the case of lead because the common tendency is to judge best performance on the basis of the lowest corrosion rate. This method fails to take into consideration the fact that lead used in chemical equipment is normally 3/16-inch thick or more. Other metals also used in chemical equipment seldom approach the thickness of lead. It can be seen that even in those cases where lead has a higher corrosion rate than another metal or alloy, it still could outlast the other metal in service because of this difference in thickness.

Designating corrosion rate according to weight loss as milligrams per square decimeter per day instead of volume loss as inches penetration per month is also misleading in the case of lead because lead has the highest density of any commonly used corrosion-resistant material. This means that what might appear to be an excessive corrosion rate expressed in weight loss of lead actually could be a very nominal rate of corrosion in terms of volume loss.

When comparisons are being made between various corrosion resistant materials it follows that an understanding and appreciation of the above will lend much to the proper interpretation of corrosion rate data.

Effect of Concentration

The concentration of a corrosive chemical and its co-influence, temperature, both are important considerations in deciding whether lead can or cannot be recommended for use with the corrosive. Apparent contradictions in lead's behavior at different concentrations are best illustrated and in part explained by example. Sulfuric acid and nitric acid are typical examples. It is well known that dilute sulfuric acid forms a film of insoluble sulfates which succeed in passifying the surface of the lead. However, as the concentration of the acid approaches 96 percent, it dissolves this protective film at a more rapid rate, thereby exposing the lead to increased reaction with the acid. For this reason lead may be used safely with any concentration of sulfuric acid as long as it does not exceed 96 percent at room temperature. An example of typical service is shown in Figure 1. The lead linings in the chambers of this acid plant after 47 years of service showed an average loss in thickness of only 1/128 inch or, expressed in inches pene-

* A Paper Presented at the [illegible] Annual Conference [illegible] April [illegible]

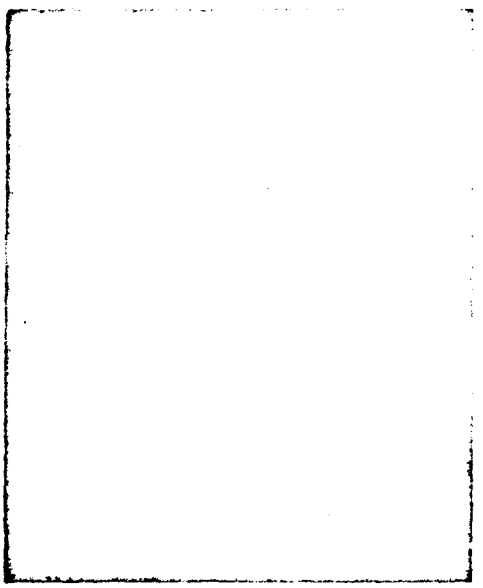


Figure 1. Interior of a lead-lined sulfuric acid chamber originally put into service in 1884. The 6-lb. lead showed an average loss in thickness of only 0.0078 inches. Patches had been applied to only about 15 percent of the area in the intervening years. This equipment was later replaced by more efficient Mills-Packard chambers.

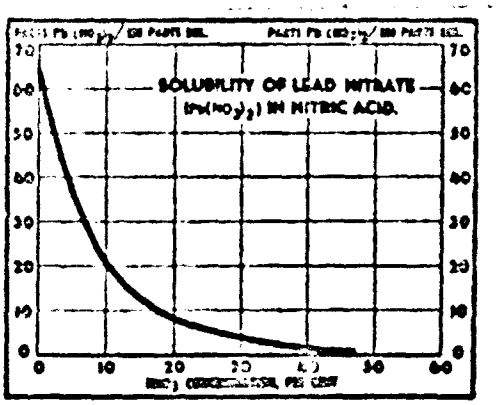


Figure 2. Solubility of lead nitrate ($Pb(NO_3)_2$) in nitric acid. Parts of lead nitrate per 100 parts of solution are plotted against nitric acid concentration in percent.

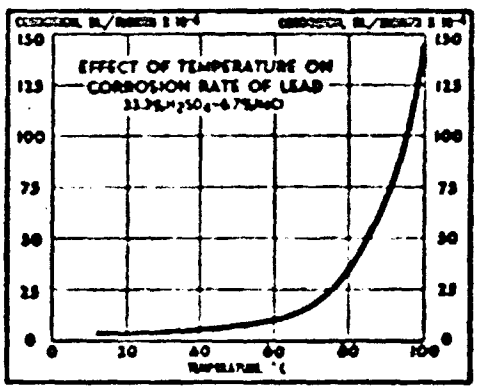


Figure 3. Effect of temperature on the corrosion rate of lead in a solution of 33.3 percent sulfuric acid plus 6.7 percent sodium chloride.

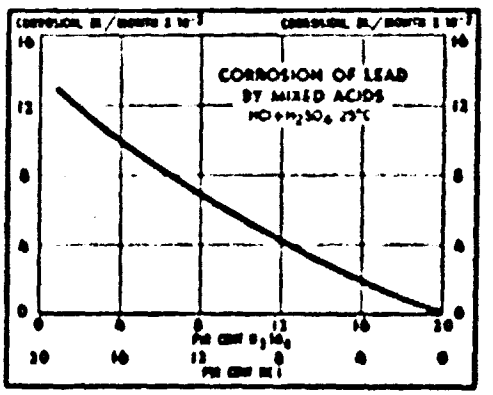


Figure 4. Corrosion of lead by mixed acids, hydrochloric and sulfuric at 25° C varying in concentration from 0 to 20 percent.

tration per month, 14 x 10^{-4}. Lead satisfactorily resists hot acid of all strengths up to 85 percent with temperatures up to 220° C. (428° F.).[3] This case typifies the reaction of lead with most corrosives including chromic acid, sulfurous acid, phosphoric acid (up to 85 percent), and others.

Dilute nitric acid, on the other hand, also reacts with lead to form lead nitrate, but the salt in this case is non-adherent and somewhat soluble in the acid and therefore offers little protection to the metal from further reaction. Concentrated nitric acid in the range of 52 to 70 percent by weight has little effect on lead at room temperature presumably because the solubility of the nitrate decreases with increasing acid concentration. (See Figure 2.) Acetic and hydrofluoric acids and sodium bisulfate parallel nitric acid in their reaction with lead.[3]

Effect of Temperature of Corrosive

Since chemical reaction rates are geometrically proportional to temperature, it follows that an increase in the temperature of the corrosive, concentration being maintained constant, almost invariably increases the corrosion rate. The rate of corrosion in inches penetration per month of lead exposed to a mixture of dilute sulfuric acid and sodium chloride at increasing temperature is shown in Figure 3.[3] Regardless of a safe concentration range, it is important before specifying lead for use with a corrosive that the temperature of the corrosive be known and taken into consideration.

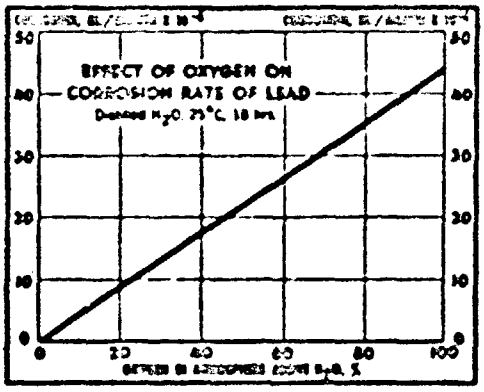


Figure 3. Effect of oxygen in distilled water at 25° C on the corrosion rate of lead. Percentage of oxygen in the atmosphere above the water is plotted against corrosion rate. Specimens were tested for 10 hours.

Effect of Mixed and Impure Corrosives

As a general rule it may be stated that in mixtures of corrosives the various constituents will react with lead as they would normally in the unmixed state. Figure 4 shows the corrosion of lead by mixed sulfuric and hydrochloric acids.[4] The corrosion rate decreases as the percentage of the sulfuric acid in the mixture increases since lead is more resistant to this acid than it is to hydrochloric.

Corrosives containing comparatively small percentages of other constituents occasionally can be deleterious to lead. Of these, liquids containing dissolved gases, particularly oxygen, are the most important. Figure 5 shows the effect of oxygen on the corrosion of lead submerged in distilled water at room temperature.[4]

Table I illustrates the effect of aeration and agitation on lead in a weak acetic acid solution at room temperature.[5]

Tests were run for a 100-hour period.

TABLE I

Quiet immersion	8	a 10^{-4} inches/month
Spray	25	" " " "
Aerated	37	" " " "

Tests with phosphoric acid have brought out the fact that impure acid is better resisted by lead than is the pure acid. The impurity in this case is primarily sulfuric acid carried over from the conversion of superphosphate.

In one contact sulfuric acid plant a corrosive liquor at a temperature of 52° C (125° F) saturated with sulfur dioxide and containing in addition 56.5 g per l sulfuric acid, 1.9 g per l chlorine and 4.1 g per l ferrous iron plus occasional traces of fluorine has been handled in lead equipment with little or no evidence of corrosion for more than ten years.[6]

Fatigue and Stress Corrosion

Because lead has a relatively high linear coefficient of thermal expansion (29 x 10^{-6} per degree C, 17 to 100° C,[3] or approximately three times that of steel) it undergoes considerable movement when subjected to severe cyclic temperature changes. It is this differential in expansion rates which largely accounts for the occasional cracking of lead due to buckling. Adequate and proper strapping serves practically to eliminate or minimize this effect. Other factors which occasionally contribute to fatigue conditions include vibration such as that transmitted by nearby machinery, stirring equipment, etc. and strain induced as a rule by inadequate support of hanging sheet lead.

Fracturing caused by repeated bending is hastened by simultaneous exposure to corrosive conditions, thus resulting in a form of stress corrosion. The normal fatigue fracture of lead is intercrystalline and in a corrosive environment fresh crystal surfaces of metallic lead constantly are being exposed until the full depth of the metal is penetrated. Thus, indication of stress corrosion in lead is evidenced by more or less severe intercrystalline etching, sometimes to the point of fracture if the stress conditions are not removed or modified. Cracks from fatigue failures in lead pipe often are transverse and usually at the outside of a bend.

There are two approaches toward elimination of difficulties brought about by the above conditions:

1. Remove the source of stress.
   - a. This may be done by insulating the equipment from vibration or,
   - b. Spreading out the heating-cooling cycle or,
   - c. Lowering the peak temperature if possible.
2. If the source cannot be removed, counteract the effect by,
   - a. Providing adequate strapping to relieve stress caused by hanging or,
   - b. Use a heat-processed, bonded lead lining to counteract severe cyclic temperature changes or,
   - c. Protect the lead mechanically and thermally with a brick lining or,
   - d. Use thicker lead to reduce fiber stress.

Fatigue characteristics may vary with different alloys of lead. Chemical lead alloyed with 0.04 to 0.05 percent tellurium is amenable to work-hardening, an effect which normally takes place during the sheet rolling operation. The property of work hardening coupled with the fact that the presence of tellurium in chemical lead acts as a grain growth inhibitor, raises the fatigue resistance of tellurium lead above that of unalloyed chemical lead.

Galvanic Corrosion

Corrosion associated with the current of a galvanic cell made up of dissimilar electrodes is defined as galvanic corrosion. This also is known as "couple action." Galvanic corrosion generally is understood to consist of the sum total corrosion, which comprises the normal corrosion that would occur on a metal exposed alone plus the additional amount due to contact with the more noble metal. Since all metals are electrically conductive, the possibility of galvanic corrosion taking place when two or more dissimilar metals come in contact in the same electrolytic medium is almost always present. However, in most chemical installations using lead in a corrosive electrolyte, galvanic corrosion usually is of little consequence and ordinarily is ignored. The film which forms on lead as a result of ordinary chemical reaction, in most instances, acts as an electrical insulator. This is true especially in sulfuric acid exposure, lead sulfate being practically non-conductive.

Figure 6. These Mills-Packard towers used in the manufacture of sulfuric acid by the chamber process are constructed entirely of sheet lead supported on a steel frame. The lead is cooled externally by water flowing down the sloping sides.

Lead Specifications

Chemical Lead

The chemical properties of lead are coupled with its composition, hence, the selection of the proper grade of lead for a chemical installation cannot be left to chance. Just as with most metals, the presence of very small percentages of other metallic constituents may alter materially the chemical behavior of lead. Experiments with pure lead alloyed with very small percentages of some other metals reveal that its surface reactivity is markedly increased by the presence of these other metals. This means, for practical purposes, that when lead so alloyed is used with a corrosive, it develops a corrosion resistant film more rapidly than pure lead and also one whose characteristics such as cohesion and abrasion resistance may be altered.[5] This is probably another reason why chemical lead, the grade most commonly used by the chemical industry and containing 0.04 to 0.08 percent copper and 0.002 to 0.020 percent silver[6] is preferred to the purer corroding lead as a material for chemical construction, in addition to the fact that the presence of such fractional percentages of so-called "impurities" markedly increases lead's creep and fatigue strength. Any increase in strength naturally lowers the tendency for movement of the metal to rupture the protective film. Higher percentages of other constituents, depending upon the element, increase the rate of salt formation to a detrimental degree or in some instances alter the cohesion and abrasion resistance of the film, leading in either case to poor anti-corrosion characteristics.

Antimonial Lead

Antimonial or "hard" lead is used in place of chemical lead when greater mechanical strength is desired. Antimonial lead as used by the chemical industry usually consists of chemical lead alloyed with from 4 to 12 percent antimony. While it is less resistant to most corrosives, it does form a more rigid installation because it has greater strength at temperatures below 120° C (248° F.) and consequently has a lower tendency to creep and warp at low temperatures.[16] Also large quantities of antimonial lead are used in pumps, valves and pipe because it offers greater strength and resistance to flow abrasion than does chemical lead.

Physical Properties

Lead's performance in the chemical industry both physically and chemically has been well documented. Sufficient performance records are available to make possible a description of the behavior of lead as a corrosive handling material from the viewpoint of its physical as well as its chemical characteristics. Physical and mechanical properties cannot be overemphasized in the case of lead; in many instances they are of greater significance to the plant engineer than chemical properties.

The physical characteristics of any metal destined for use in the chemical industry determine three important factors:

1. How it will act at various temperatures and pressures.
2. In what form the metal may be fabricated best or constructed to meet the requirements demanded in No. 1.
3. The economic aspects of maintenance and replacement.

The many ways in which lead's physical characteristics influence its value to the chemical industry as a material for handling and controlling corrosives are described herewith to guide those whose responsibilities involve specifying such materials.

Temperature Limits

Lead's usefulness at elevated temperatures is limited because of its melting point. Lead melts at 327° C. (621° F.). It may be used safely at temperatures up to 230° C. (450° F.) in the absence of stress corrosive conditions. Above this temperature, corrosion resistance and strength decrease to a degree making practical use questionable. The same safe working limits apply as well to tellurium chemical lead.[6]

Antimonial or "hard" lead containing 6 percent antimony can be recommended for use only up to about 120° C. (248° F.), although it has a melting at 252° C. (486° F.). At temperatures higher than 120° C.,

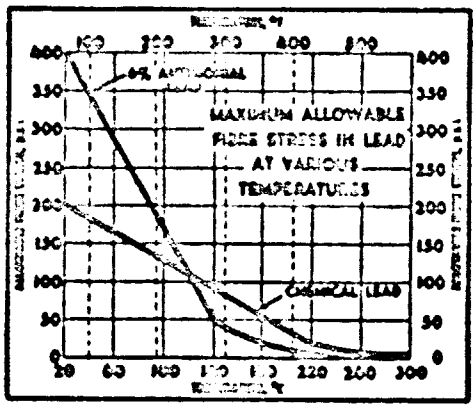


Figure 7. Maximum allowable fibre stress in chemical and 6 percent antimonial lead at various temperatures. Fifty pound saturated steam limits are at 148° C (298° F).

6 percent antimonial lead actually is less effective than chemical lead because it softens rapidly and usually corrodes more readily.

It is possible, in some types of equipment to operate in excess of the above temperatures by insulating or shielding the lead internally with acid-resistant brick or cooling the lead externally with water sprays. The lead in all Mills-Packard sulfuric acid chambers is kept cool by water flowing down the sloping sides. A typical installation is shown in Figure 6. Bonding lead directly to the shell as in homogeneous linings also permits operation at higher temperature ranges.

Pressure Limits

Steel and wooden tanks frequently are lined with lead to provide corrosion resistance. The tanks themselves should be designed to retain the hydrostatic pressure or any other pressures built up during operation of the vessel.

In deep tanks, because of the high density of lead (0.410 lbs. per cubic inch) hose linings must be strapped properly to overcome the effect of gravity. The maximum height of a uniformly cross-sectioned hose lead lining supported only from the top theoretically is 40 feet at a constant temperature of 20° C (68° F). The maximum height of an unstrapped lead lining at a constant temperature of 150° C (302° F) theoretically is 16 feet. In practice the optimum height of a hose lead lined vessel without the benefit of any support from strapping rarely exceeds 8 feet, depending upon the weight of lead.

When lead is used to handle steam or water under pressure the maximum allowable hoop or fibre stress of chemical and tellurium lead is 200 psi at room temperature (20° C [68° F]); the maximum allowable fibre stress at 150° C (302° F) is 80 psi. Use of lead under pressure at higher temperatures is not recommended.[10]

Antimonial lead (6 percent), being stronger than soft lead, has a maximum allowable fibre stress of 400 psi at room temperature, but because it has a lower melting point the allowable fibre stress is only 50 psi at 140° C (284° F).[10] Figure 7 shows the maximum allowable fibre stress for chemical and 6 percent antimonial lead at various temperatures.[10]

Lead-lined vessels often are used under vacuum. One process for recovering and concentrating sludge acids successfully uses brick-lined sheet lead under vacuum as low as 0.25 inches of mercury. Just as under pressure, it is imperative that the shell of the vessel be sufficiently strong to resist collapse due to atmospheric pressure. When heat transfer is important, homogeneously bonded lead should be used.

Effect of Rate of Flow

Because lead is comparatively soft it is susceptible to erosion by fast-flowing liquids or liquids containing abrasives. Table II shows the effect of increasing the velocity of 20 percent sulfuric acid at 25° C (75° F) across the surface of lead.[8]

TABLE II

Velocity of Solution Across Lead Surface ft./min.	Rate of Corrosion in./month x 10⁻³
8.6	35
47	17
133	36
308	86

The rates appear to fall with initial increase in velocity, but increase markedly at a velocity of 200 feet per minute. The erosion of lead pipe may be retarded by designing the system to reduce flow rate friction as much as possible, e.g. eliminate sharp bends, use larger pipe, or both. Lead pipe is especially useful when a high rate of flow is desired because it can be curved and assembled without extra fittings, and because extruded lead offers a minimum of surface friction. The relative surface smoothness of lead pipe according to the "Chemical Engineer's Handbook," is classified in the same category as glass.[9]

Fabrication and Equipment

Another very important physical characteristic of a metal destined for anti-corrosive use is its amenability to various methods of fabrication. Here lead enjoys a rather unique position insofar as one of its chief advantages over other metals is predicated on the number and variety of ways in which it may be fabricated. Sheet lead may be welded or "burned" to form a continuous lining; it may be bonded directly to another metal; it may be cast, die cast or pressure molded; it may be extruded into pipe and a variety of shapes; and it may be fastened by welding, flanging, bolting or soldering. Once installed, lead chemical equipment is easily repaired with a welding torch and requires no annealing or subsequent heat treatments.

Soldering and Welding

In chemical applications, at least where corrosion is a factor, soldering is of little value because of the relative ease with which the tin lead eutectic is attacked, plus the fact that tin substantially lowers lead's melting point. Lead welding, commonly called

lead "burning," is a simpler and much more satisfactory method of joining lead to lead without introducing any foreign metals. The ease with which this is accomplished when an experienced lead welder is used has contributed much to the widespread use of lead linings. Lead welding permits the fabrication of continuous impervious linings in vessels constructed of metals stronger than lead but without its corrosion resistance. Figure 8 shows lead welders working on a typical sheet lead installation. Many chemical plants operating with considerable lead equipment train and maintain their own lead welders for making minor repairs. When installing or building new equipment, they generally bring in more experienced lead welding contractors who are specialists.

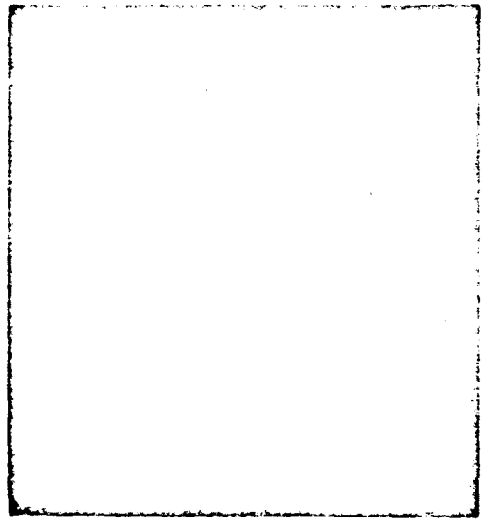
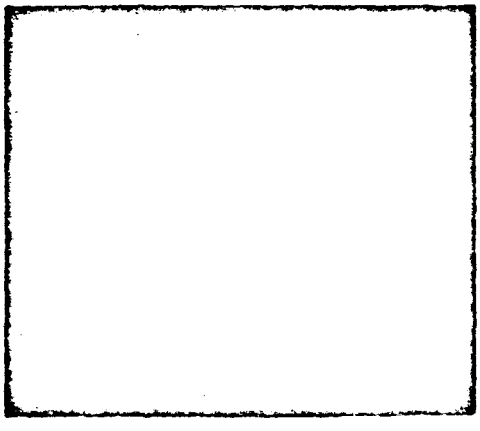


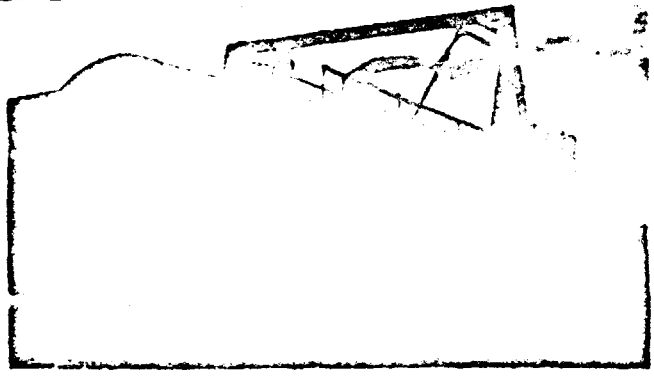
Figure 8. Welding the seams of a typical horse sheet lead-lined tank. The man at upper right is preparing the seams for welding by stripping the lead clean.

Sheet Lead Linings

Sheet lead for lining all types, shapes and sizes of chemical equipment usually comes in rolls ranging from 8 to 12 feet wide and up to 60 feet long, depending on the thickness of the sheet. Twenty feet is generally a standard roll. Thickness varies from 1/50-inch to 2 inches, or measured in the parlance peculiar to the lead industry—½-lb. to 120-lb. lead. As an approximate rule of thumb, one square foot of lead 1/64 inch thick weighs about one pound and is called 1-lb. lead; ¼ inch lead is called 16-lb; etc. Most sheet lead is ordered cut to the size that will be used ultimately by the consumer. In some special applications, such as in the walls of Mills-Packard sulfuric acid chambers, a single sheet may be rolled with several different thicknesses.[6]

From the construction viewpoint, the most important aspect of effective sheet lead lining is the provision of adequate and proper support, usually by strapping. Specifications for lead linings depend on such factors as size of equipment, size or weight and grade of lead, temperature, corrosive conditions, type of shell (wood or steel), type and location of strapping, and others. Detailed discussion of such specifications warrants a special paper of its own. Generally speaking, sufficient strapping should be used in the right places to insure reasonable service performance and minimum stress corrosion, assuming of course, that the lead is known to be resistant to the





Figures 9 10. Lead lined steel storage tanks 10½ feet in diameter and 36½ feet long, interior view. Figure 10, above, method of strapping. Note that the overhead strapping which must support the weight of the lead consists of 10 straps 1 foot 3 inches apart whereas the bottom belt is fastened with only 6 straps 2 feet 9 inches apart. The vertical end straps are 1 foot 9 inches apart.

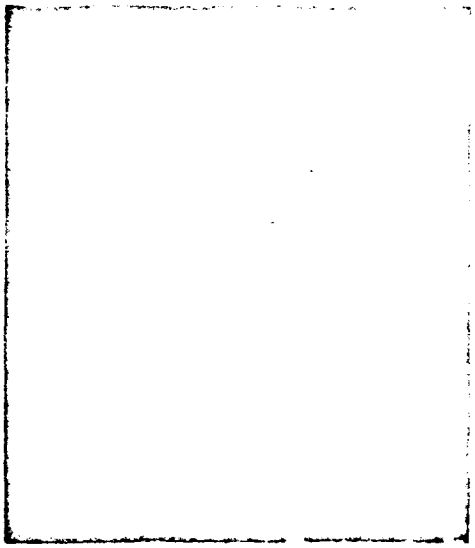


Figure 11. A complex piping system for recirculating corrosive electrolyte in a modern plating plant. All pipe and valves are made partially or entirely of lead.

corrosive under the same conditions of concentration, temperature and agitation to be encountered in that particular service. Figures 9 and 10 show an example of good strapping practice. The top strapping in Figure 10 which must support the weight of the sheet lead is placed at closer intervals than the bottom strapping which simply holds the lead in place, its weight being supported by the steel shell of the tank.

A case on record illustrates the importance of adequate strapping. The process is an especially severe one for a lead lining: the manufacture of alum by reacting sulfuric acid with alumina in a steam agitated lead-lined steel tank. By removing the original 16-lb lead lining which was vertically strapped every four feet and installing 22-lb. lead with the distance between straps reduced to two feet the service life of the vessel was tripled.[9]

Horizontal strapping in lieu of vertical strapping seldom is used, particularly when under-hand welding is involved. Occasionally in tanks more than 10 feet deep one or two horizontal straps are used in conjunction with the usual vertical strapping to help support the weight of lead.[10]

Homogeneous Linings

Under severe temperature conditions, particularly when wide fluctuations are necessarily used over a short period of time such as in batch processing and various cyclic reactions, two different methods may be adopted to prevent undue shortening of the lead's normal service life. The method most often used and one which has performed very well in service is to bond the lead to the steel shell of the equipment, forming what is termed a homogeneously bonded lining. For high temperature service (up to 320° C. [450° F.]) lead is bonded directly to the steel; at lower temperatures the lead may be joined to the steel with the aid of a thin lead-tin solder film. While this method of lining with lead is more expensive, the extra cost is usually more than compensated for by a substantial increase in the life of the equipment.

Homogeneous lead linings always should be employed for jacketed vessels where heat transfer is important because any air space between the lead lining and the shell of the vessel results in a reduction in the efficiency of heat conduction. Many bottom-jacketed reaction tanks are lead-lined on the sides and bonded on the bottoms.

Acid-Brick Linings

A second method of protecting lead-lined vessels from temperatures close to lead's softening range or from erosion effects is to cover the lead with an inner lining of special acid-resistant brick. A natural question is: If the bricks are acid-resistant, why use a lead lining? Unfortunately practically all bricks will spall or crack after repeated heating and cooling and eventually, even after operation at continuous temperature, tiny cracks will develop in the brick lining permitting the corrosives to seep through to the outside. Bricks also will spall when they absorb saturated solutions which crystallize on cooling. As a matter of fact, no cemented conglomerate such as brick can be as impervious to liquids as a metal. With nothing to protect it, the supporting shell of the vessel will be attacked by the seeping corrosive and eventually require expensive repairs and probably replacement. The lead acts as insurance against this occurrence. Any seepage will be retained by the lead until the brick lining can be repaired.

A large by-product sulfuric acid plant has been using a brick-lining over lead in its humidifying chamber for handling corrosive sulfur dioxide and sulfur trioxide at 290° C. (554° F.). The linings consist of 20-lb lead with three courses of brick on the bottom giving a total thickness of 9 inches and a single 12-inch course over 10-lb. lead on the lower sides thinning to a 9-inch course above. The thicker 12-inch lining is simply to provide extra support for the brick above. This equipment has been in use for eleven years.[10]

Lead and Lead-lined Pipe

Lead is extruded readily into various shapes and large quantities of extruded lead pipe are used by the chemical industry. Sizes are limited only by extrusion equipment and may include a large number of combinations of wall thickness and outside diameter as well as shapes of cross section. An advantage of lead pipe is that it is readily bent to conform to intricate design specifications. Figure 11 illustrates a complex pipe and valve system made up entirely of lead. Because of lead's weight, it is frequently advisable to support it either by strap hangers or continuous support such as laying it in steel channels. This is why lead lined steel or cast iron pipe frequently is used when the corrosion resistance of lead is demanded.

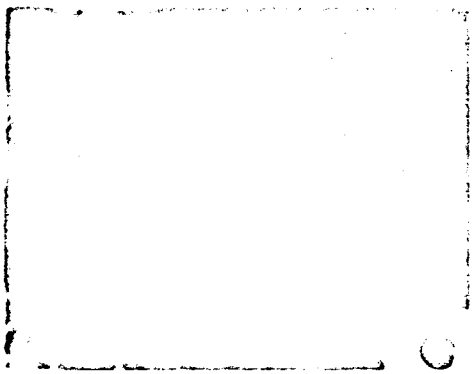


Figure 12. View through the manhole of a brick-lined reaction vessel 10 feet deep and 5½ feet in diameter used for heating mixtures of sodium bichromate and sulfuric acid at 160° C (212° F). Two bismuth-lead coils installed in 1939 are still being used to heat the charges of solutions with steam under 30 pound pressure. Cooling water is pumped through the coils after the reactions are completed. The steel agitator is homogeneously bonded with chemical lead to mild steel.

but when the temperature is high and the expense of supporting the pipe is disproportionate. Steel or iron pipes with lead linings inside are made by one of two methods: extruded lead pipe hydraulically expanded inside an iron or steel pipe, or homogeneously bonded to it.

Lead Heating Coils

Lead pipe has found wide acceptance for use as heating or cooling coils. Figure 12 shows the lead steam coils used for heating a large brick-lined vessel with a rounded bottom. Note the cast lead form used to support the coils. Maximum steam pressure and corresponding temperature limits for different pipe sizes are shown in Table III.

Table III

Inside Diameter of Lead Tube	Outside Diameter of Lead Tube	Weight per Foot		Maximum Steam Pressure, p.s.i.	Corresponding Temperature Limit, °F.
		Lbs.	Ozs.		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

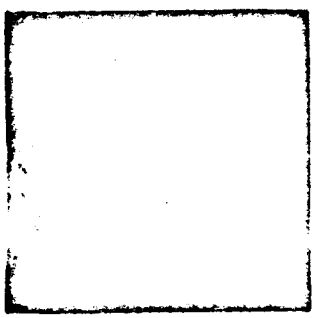
Copper coils covered with bonded lead have been developed for greater thermal conductivity and strength at higher steam pressures without sacrificing corrosion resistance. Such coils are operated up to 150 pounds steam pressure.

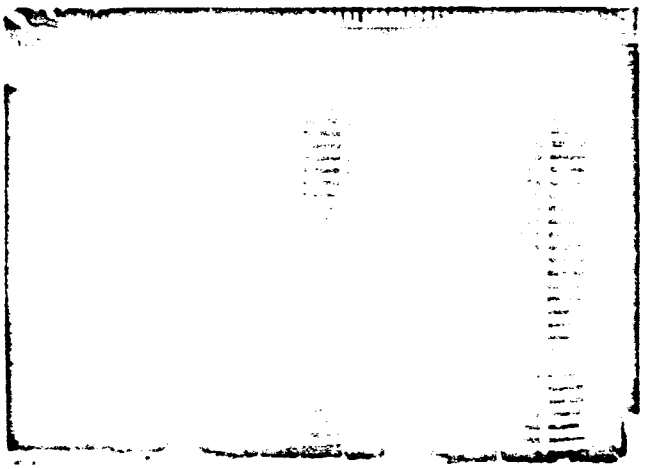
One of the latest developments illustrated in Figures 13 and 14 consists of using two lead pipes, one within the other, resulting in a double action heating and cooling heat exchanger. The inside pipe is extruded with its cross-section in the shape of a six pointed star with a round hole in the center. In this manner the cross-sectional area of the space between the two pipes very nearly equals the cross-sectional area of the inside of the inner pipe. The points of the star also serve to keep the two pipes concentric. With this arrangement it is possible to permit countercurrent heating in one pipe while cooling in the other.

Ribbed and finned lead pipe are used in many systems requiring greater surface area. Lead sheathed electric heating devices have been used successfully in place of steam heated coils in some installations where raising steam is difficult or hazardous or where electricity is inexpensive.

Castings and Valves

Large quantities of lead are used by the chemical industry in the form of castings. Ordinary chemical





Figures 13 & 14. Heat exchanger coils consisting of one lead pipe within another permitting countercurrent flow of a corrosive content. The cross sectional view of the exchanger cut in Figure 14 shows the specially shaped extruded inner pipe in position.

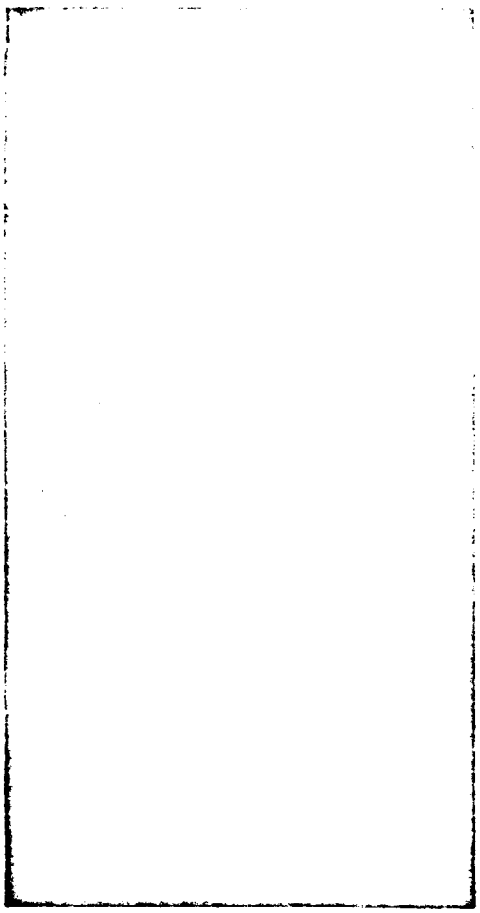


Figure 15. Six-section-tee evaporator made entirely of cast 8 percent antimonial lead and used for concentrating titanium sulfate solution.

lead, usually too soft for this purpose, is alloyed with various percentages of antimony. Lead hardened in this manner is cast into pumps and valves as well as many special shapes and fittings. A typical piece of cast lead chemical equipment shown in Figure 15 is an evaporator for concentrating titanium sulfate solution. It is made entirely of separate castings of 8 percent antimonial lead bolted together into one unit measuring 4½ feet in diameter and 7 feet high. Almost 35,000 pounds of metal were required to make the castings.[16] Even larger cast lead evaporators six feet to eight feet in diameter are quite common. Cast lead plate and frame filter presses and cast lead rotary vacuum filters are built in all sizes.

Lead valves frequently are equipped with plugs and seats made of abrasion resistant materials such as Lucite, Bakelite, Hastelloy and others, thus reducing the wear on these parts.

Economic Aspects

The economic aspects of maintenance and replacement hinge on both the metal's physical characteristics and its salvage value. Lead suffers very little from change in weight or structure due to corrosion; thus it can be maintained at low cost or salvaged at a high value.

Fabrication costs are low in the case of lead. Present prices show that the pig lead or raw material represents as much as 80 percent of the cost of fabricated sheet and pipe.[17]

Scrap lead is easily remelted and refined and volume losses under most corrosive conditions are so slight that as a result lead has an unusually high salvage value which may run as high as 75 percent of the original cost of new sheet and pipe, depending upon market conditions.

Summary and Conclusions

A study of the successful performance of lead equipment in the chemical industry shows that such performance is intimately associated with lead's physical characteristics as well as its chemical or corrosion characteristics. Lists of chemicals with comments and data describing their reaction with lead, such as appeared in the December, 1946 issue of Corrosion, are available.[18] Lead companies and fabricators and the Lead Industries Association may be consulted. Inasmuch as advice can at best be only a prediction based on past performance, the most practical procedure is to test a sample of the lead under conditions as close as possible to actual service.

No set rule can be stated governing the reaction of lead with all corrosives. Comparative corrosion rate data based on volume loss or weight loss can be misleading in the case of lead insofar as it is thicker and more dense than other corrosion resistant materials. Generally, the corrosion rate increases with increase in temperature. The effect of concentration varies with the corrosive. Chemicals containing dissolved oxygen usually lower lead's resistance. Fatigue accompanied by corrosion promotes stress corrosion, a condition which may be controlled by removing the source of stress or counteracting its effect. Galvanic corrosion in the case of lead is seldom encountered because an insulating coating normally develops which prevents or minimizes couple action.

While lead has certain physical limitations as a construction material, they usually can be overcome by proper installation. The maximum allowable fibre stress for chemical lead is 200 psi at room temperature; antimonial lead, being stronger, has a maximum allowable fibre stress of 400 psi at the same temperature. Chemical lead's usefulness at high temperatures is limited to about 230° C. (450° F.) while antimonial lead (6% Sb), because of its lower melting point, is limited to about 120° C. (248° F.). The erosion of lead by fast-flowing or abrasive liquids may be retarded by proper design.

Lead can be fabricated easily to meet special conditions. Sheet lead lined vessels usually are supported by vertical strapping, the type and location of which is very important. Conditions such as temperature

fluctuation, high pressure or vacuum, or heat transfer can be met with homogeneous linings or, excepting heat transfer, by a brick lining over the lead. Lead pipe, heating coils, castings and valves can be made to cope with a variety of special conditions.

Because of the manner in which lead corrodes coupled with its smelting characteristics lead in all forms can be reclaimed and sold as salvage at a high return.

Therefore, if lead's mechanical and physical properties are recognized in making installations, it is widely favored as a material of chemical construction because chemicaly it is little affected by so many corrosives.

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