LEAD INDUSTRIES ASSOCIATION
292 MADISON AVENUE
NEW YORK 17, N. Y.

February 23, 1961

CHEMICAL BULLETIN NO. 76

SUBJECT: "HOW TO CHOOSE LEAD LININGS FOR PROCESS VESSELS"

To Members of the Lead Industries Association:

Attached is a reprint of an article with the subject title which appeared in the January 23 issue of "Chemical Engineering" magazine. We believe that it provides a useful round-up of information on the methods of using lead linings under the varying conditions to be found in the chemical process industries. It will also be used for distribution at our booth at the National Chemical Exposition next fall and in answering inquiries on chemical construction received by the Association.

Additional copies in quantities up to 25 are available free of charge as long as our supply lasts, and larger quantities at five cents per copy.

Very truly yours,

Secretary

RLZ:JRH

Att.

How to Choose Lead Linings for Process Vessels

There are five ways to line a vessel with lead—each has advantages and limitations. Choice is made based on lead's properties and operating conditions in the vessel.

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Lead is an obvious choice for lining many reaction and storage vessels, particularly where severe corrosives must be contained. But specifying the correct type of lead for an application is only part of the job. To avoid costly and premature failures, the type of lining construction should also be selected by the design engineer.

This selection must be based on an understanding of lead's chemical and physical properties—and how they relate to the corrosive and to stresses that will develop in the operating vessel.

▶ **Types of Construction**—There are five basic types of construction used for installing lead linings in chemical-processing vessels.*

Lead lining may be loose sheets of lead draped inside a shell of steel, wood, or concrete, with lead burned along the seams that are with or without internal supports of lead-covered steel; as sheets of lead and steel or lead and copper continuously bonded together face to face (commonly referred to as homogenously bonded); as a lining shell of sheet lead externally supported by a cage construction; or as a membrane that envelopes an acid-brick lining.

Loose lead-sheet construction is the least expensive but it is limited in practical application to vessels of moderate size and conditions that do not impose extremes of temperature, abrasion, pressure or vacuum.

The theoretical maximum length of a lead sheet, of uniform cross section supported only from the top, is 40 ft., at 68 F. In practice, however, it is seldom feasible to suspend lead sheet more than about 10 ft. without strapping. And excessive strapping requirements tend to offset the economies of this method.

However, new methods for fastening strappings reduce time and cost for this operation by 70%. Studs may be driven home with a power tool, which eliminates drilling and lining up bolt holes prior to fastening.

▶ **Caged Lead**—Cage construction consists of an open exterior framework of steel flats and angles welded together to support the lead lining. Supporting members are spaced closer together toward the bottom to accommodate increased hydrostatic pressure. (Expanding and contracting lead lining is free to slip into stress-free posture within its [illegible] cage.) Open construction allows for excellent heat exchange, while leaks are readily seen and repairs easily made. Cost is low, comparable to that of loose sheet lining.

An ingenious example of cage construction that makes the most of heat-transfer possibilities is the Mills-Packard tower, designed as a reaction chamber for manufacture of sulfuric acid by the chamber process. The tower is tapered so that excess heat generated inside is dissipated by a film of water that flows down the exterior surface.

▶ **Bond for Vacuum**—Homogeneously bonded sheets are usually lead on steel or lead on copper, although other combinations are possible. Steel provides strength; copper has desirable thermal properties.

Steel is cleaned by shot blasting or sometimes by pickling in 10% sulfuric acid. Copper is also chemically cleaned. Lead is then applied by a burning bar or, for larger

* Photo above shows lead-lined fume duct. Sheet lead strip covers steel stud fastened to the vessel shell. Strip is burned to the lead lining.

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292 Madison Ave., New York 17, N.Y.

Costs, conditions, requirements for five types of lead linings—Table I

	Loose Sheet	Steel Bonded	Copper Bonded	Cage	Brick
Cost factors					
Initial	Low	Fairly high	Fairly high	Low	Fairly high
Inspection	Low	Fairly high	Fairly high	Very low	Fairly high
Repair	Low	Low	Low	Low	High
Hostile conditions					
High temperature	Fair	Excellent	Excellent	Poor	Excellent
Thermal shock	Fair	Excellent	Excellent	Poor	Excellent
High pressure	Excellent	Excellent	Good	Poor	Excellent
Vacuum	Poor	Excellent	Good	Poor	Good
Physical shock	Poor	Excellent	Excellent	Poor	Good
Erosion	Poor	Fair	Fair	Poor	Excellent
Corrosion	Excellent	Excellent	Excellent	Excellent	Excellent
Design requirements					
Insulation	Fair	Fair	Poor	Poor	Excellent
Heat transfer	Excellent	Excellent	Excellent	Excellent	Poor

areas, simply poured over the other metal. The lining surface is smoothed by peening and/or scraping.

Bonded linings are, of course, more expensive but are superior on almost all counts and will usually remain serviceable much longer than other types. Since there is no air gap between the two metals, uniform heat exchange is good. Rigidity, particularly with a steel backing, permits operation under high vacuum. For lead bonded directly to steel, operating temperatures as high as 608 F. are permissible, and the lining won't creep or crawl up to 450 F. Rapid temperature fluctuations, mechanical shock, and vibration are tolerated. This type of construction is also recommended for very tall structures where heavy acid-brick lining would impose formidable stresses.

Design engineers are advised not to skimp on the weight of lead specified in bonded linings; cost of such linings is essentially that of the bonding process.

Modern techniques have largely overcome objections to the difficult job of locating imperfections in the bond. An unbonded area may be identified by a bubble that forms when the internal temperature is raised to 490-500 F. or, in a pressure vessel, when the internal pressure is raised to 680 psia. and suddenly released. Efficient sonar and radiation methods of inspection are also available.

Brick for Heat—Sustained operation involving high temperature, erosive attack, and extremes of corrosive attack and thermal shock are best withstood with acid-brick construction. The brick lining, usually one or two courses, insulates not only the system as a whole but the enveloping lead membrane as well, permitting operation at interior temperatures well in excess of the melting point of lead.

Acid-brick and lead are functionally complementary to one another. Acid-brick is resistant to polar organic chemicals but is attacked by nonpolar organics, to which, however, lead is resistant. The total system tolerates the most severe corrosive attack, as, for instance, both acids and alkalis in the same vessel. However, brick spalls due to rapid temperature changes, sustained operation at extreme high temperature, or absorption of saturated solutions that crystallize on cooling. Best grades of acid-brick are intentionally made 3 to 4% porous for increased resistance to thermal shock. The impermeable lead membrane contains the seepage.

If extreme high temperatures are expected, a brick-lined vessel should be built on an elevation so air can circulate freely beneath it. Otherwise, conductive heat may build up deep in the vessel. Sufficient brick must be used to prevent surface temperature of the lead from exceeding 125 F. Bottom of the vessel should be dished if extreme pressure is a factor. Also, it is sometimes desirable to design the lining so elongation of the bricks will close the gap between brickwork and lead membrane, holding the lead under compression for greater support.

Asbestos paper is bonded to the lead with potassium silicate solution to prevent contact with sodium ions in acidproof or furan-resin cements. While asbestos is not required with sulfur-base cements, two or three layers of nonburn paper should be used to form a protective cushion against abrasion.

Some of the new inspection methods developed for bonded linings have been equally effective in simplifying maintenance of brick-lined vessels.

Table I provides a check list of the relative strong and weak points

Leads's resistance to various chemicals—Table II*

Excellent

Sulfuric acid (to 96%)	Dry ammonia gas
Boron solutions	Dry chlorine
Superphosphates	Carbon dioxide
Aluminum sulfate	Dry oxygen
Sulfur dioxide	Sulfur trioxide
Sulfite liquor	Sodium chloride
Acetone	Magnesium sulfate
Alcohol	Calcium carbonate
Benzene	Sodium carbonate (dilute)
Toluene	Bisulfates (dilute)
Gasoline	Chromates (dilute)
Ether	Sulfates (dilute)
Phenol	Phosphates (dilute)
Pyridine	Boric acid
Urea	Salicylic acid
Chromic acid	Sulfurous acid
Oxalic-sulfuric acid	Tartaric acid
Phosphoric acid	
Acetylene	

Good

Chlorine bleach	Ammonium phosphate
Nitroglycerin	Sodium hydroxide (up to 30%)
Naphthalene	Potassium hydroxide (up to 30%)
Wet chlorine gas	Nitric acid (concentrated)
Wet ammonia gas	Hydrocyanic acid
Carbon tetrachloride	Hydrochloric acid (up to 20%)
Dry hydrogen chloride	Arsenic
Calcium chloride	
Fatty acids	
Sodium sulfide	
Ferrous chloride	

Fair

Hydrogen peroxide	Ammonium nitrate
Wet oxygen gas	Ammonium chloride (up to 10%)
Cold bromine gas	Calcium hydroxide
Sodium sulfite (up to 20%)	Ammonium hydroxide
Sodium hyposulfite	Tannic acid (conc.)
Sodium chlorite (dilute)	Hydrofluoric acid
Nitrates	Formic acid (conc.)
Carbonic acid	Acetic acid (glacial)

Poor

Hydrochloric acid (pickling strength)	Sulfuric acid (over 96%)
Magnesium chloride	Hydrochloric acid (over 20%)

Not Recommended

Chloride bleach	Ferric chloride
Potassium permanganate	Nitric acid (dilute)
Nitrobenzene	Acetic acid (dilute)
Sodium hypochlorite	

*Chemicals are listed according to severity of attack. Least severe is listed first. Lead is chemical grade.

of each of the five major types of lead-lined construction.

▶ **Composition Important Factor**—Aside from construction methods, composition of the lead itself may be varied to enhance certain properties.

Chemical-grade lead or acid-copper-grade lead, containing from 0.04 to 0.08% copper and from 0.002 to 0.02% silver, forms a protective film faster than pure lead. The film adheres firmly and resists abrasion.

Trace elements also increase lead's creep and fatigue strength. Maximum allowable fiber stress at room temperature is 200 psi. Usefulness is limited to temperatures up to about 446 F. A 25 to 35% sulfuric acid solution will form a complete sulfate film on this grade in from 9 to 10 hr. at 70 F.

▶ **Antimony-Pb for Valves**—Lead containing 4 to 12% antimony is preferred for valves, pumps and other components requiring a certain degree of dimensional precision. This grade has greater hardness, rigidity, mechanical strength, and resistance to erosion and abrasion at ordinary temperatures. In addition, it creeps and warps less than pure lead.

However, antimonial lead is only advantageous up to about 248 F., because it softens rapidly at higher temperatures. At these higher temperatures, its mechanical strength is only equal to that of chemical-grade lead.

Moreover, antimony lowers lead's chemical resistance. Antimonial lead is preferred for handling sulfuric acid only in very low concentrations (optimum resistance with 3% antimony). Maximum allowable fiber stress of antimonial lead is 400 psi. at room temperature. A complete sulfate film is formed on antimonial lead by 25 to 35% sulfuric acid in from 1 to 1½ hr., at 70 F.

Resistance to metal fatigue is promoted by addition of 0.04 to 0.05% tellurium to the lead. Tellurium acts as an inhibitor of grain growth and also makes the lead amenable to work hardening.

▶ **Corrosion Resistance**—And, of course, lead's corrosion resistance must be considered in any lining installation.

As with aluminum and stainless steel, lead's resistance to chemical attack is based not on its chemical inertness but rather on its chemical reactivity. Lead reacts very quickly with most corrosive agents to produce resistant, insoluble salts that form nonporous protective films over the pure metal. It is this film, not the metal itself, that resists further attack.

Lead is highly recommended for handling sulfuric acid under most conditions. This acid reacts with the metal to form an adherent, impermeable film of lead sulfate that guards the metal against further attack. In acid concentrations up to 96%, corrosion of lead is negligible at room temperature. In stronger concentrations, acid apparently reacts with the film.

Nitric acid presents a more complex situation. Dilute nitric combines with lead to produce lead nitrate, which adheres poorly to the metallic surface and is somewhat soluble in the dilute acid. Lead is, therefore, not recommended for handling dilute nitric. But concentrations from 52 to 70% by weight do little damage to lead vessels. This is, apparently, because solubility of lead nitrate in nitric acid decreases as concentration of the acid increases (Fig. 1).

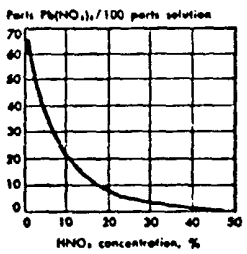
Dissolved gases, particularly oxygen, may affect rate of corrosion substantially. Corrosion rates of lead in distilled water at 77 F. vary directly with the oxygen content of the atmosphere above the liquid.

▶ **Acid Bath Protects**—The corrosion pattern observed at a typical sulfuric acid plant illustrates the effect of oxygen in the vapor phase and suggests a useful protective technique.

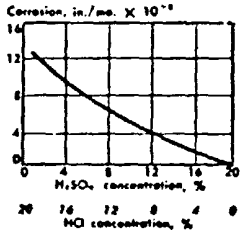
Where the liquid acid was in contact with a lead lining, the lining was perfectly protected by a film of sulfate salts formed by reaction of the metal and the acid. However, severe corrosion was observed higher on the walls of the vessel where the lining was in contact with the vapor phase. The reaction products formed in the presence of free oxygen in the vapor phase were unstable and formed an inadequate film.

One solution to this problem was to maintain the liquid level at the top of the vessel or periodically to

Lead nitrate dissolves in nitric acid—Fig. 1



Lead corrodes in mixed acids—Fig. 2



raise it to the top long enough to renew the impermeable film.

This suggests the following method of pretreating lead for use in contact with corrosives that do not form an impermeable protective film: fill the lead-lined vessel with 25 to 35% sulfuric acid and maintain temperature at 70 F. This will form a complete sulfate film on chemical-grade lead in 9 to 10 hr. Only 1 to 1½ hr. is required to achieve the same effect on 9% antimonial lead.

▶ Additive Effects—In general, while lead is highly resistant to corrosives that form insoluble sulfates or phosphates, it does not perform too well under attack by solutions that form soluble nitrates, acetates or chlorides.

Also, effect of attack by a mixture of corrosives is additive. For example, lead is protected by sulfuric acid, corroded by hydrochloric acid. Resistance varies linearly as the ratio of sulfuric to hydrochloric in a mixture of acids (Fig. 2).

This, of course, assumes no complications involving products of the reaction between lead and the separate solutions, or between one solution and another. In such cases, effects of the intermediate and final products must be considered independently.

Table II classifies resistance of lead to many of the chemicals commonly handled in the chemical processing industry. Performance in a particular application will depend, in addition, on temperature, erosion, and mechanical abuse. In most cases, corrosion increases with increase in temperature.

▶ Watch Erosion Effect—Erosion may become an important factor when the solution is agitated or flowing through the vessel. While it is true that lead's corrosion resistance is essentially "self healing," it should be remembered that formation of the protective salt film consumes lead. If the film is constantly eroded and replaced, lead will be consumed progressively. Factors that determine rate of erosion include rate of flow and entrainment of particulate matter.

The relationship between rate of flow and rate of erosion may not be linear. For example, in laboratory tests, for 20% sulfuric acid at 77 F., the following is true for chemical-grade lead.

Flow Velocity (Ft./Min.)	Corrosion Rate (In./Mo.)
8.4	0.00055
97	0.00017
155	0.00016
300	0.00086

Mechanical abuse may, of course, contribute to corrosion more than erosive attack. Design and operating procedures should minimize any mechanical damage.

▶ Smooth as Glass—Due to its malleability, lead presents an uncommonly smooth surface—one reason why it is often chosen for process equipment. Smoothness of the interior surface of extruded lead pipe is rated about even with glass.

Aside from its softness and malleability, the more pertinent mechanical properties of lead are its coefficient of expansion (about 16.3 x 10^{-6}/F.), its melting point (620 F.) and its density (0.410 lb./cu. in.). In absence of stress-corrosion conditions, it is safe to use lead up to about 446 F.

Related to these physical characteristics are two factors that should be kept in mind when making comparisons of lead versus other materials. Such comparisons usually are based either on mass lost to corrosion per unit time, or depth of penetration of corrosion per unit time. But loss of material of a given mass is relatively insignificant in the case of lead, since lead is so heavy. And a given depth of penetration is not as serious in a lead lining, as a rule, since lead linings are ordinarily much thicker than those of other materials.

Finally, economic considerations favor lead. It is inexpensive and easy to work. And scrap recovery usually rebates about 50% of original material cost.

Meet the Author

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From 1947 to 1956, he also served as secretary and treasurer of the Metal Powder Assn. He is presently a member of AIME, ASTM, IM (British).

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Reprinted from Chemical Engineering, Jan. 9, 1961