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TELEPHONE — AREA CODE 212
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February 10, 1965

SUBJECT: REPRINT "LEAD IN MODERN CHEMICAL CONSTRUCTION"

To Members of the Lead Industries Association, Inc.:

The enclosed article "Lead in Modern Chemical Construction" has been prepared by L.I.A. and reprinted from the Encyclopedia of Chemical Processing Equipment, just published by Reinhold Publishing Corp. The article describes types of lead products, design criteria for lead installations, sheet and bonded constructions, pipe and coil installations and inspection and testing methods.

The reprint is being distributed to a list of 1,640 chemical companies and chemical engineers. It will also be distributed at appropriate trade shows and used to answer inquiries received by L.I.A.

You may obtain 25 copies of the reprint free of charge, and additional copies are available at our cost of 10 cents per copy.

Very truly yours,

Robert Travis

RT:bd
Enc.

Look Ahead with Lead

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LEAD IN MODERN CHEMICAL CONSTRUCTION

Reprinted from

The Encyclopedia of

CHEMICAL PROCESS EQUIPMENT

Published by

REINHOLD PUBLISHING CORPORATION, NEW YORK

Distributed by

LEAD INDUSTRIES ASSOCIATION, INC.

292 Madison Ave., New York, N. Y. 10017

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Lead has been an important material for handling corrosive chemicals since the beginning of the chemical process industries. It was used for the first commercial sulfuric acid chamber constructed in 1749 and subsequently has seen more than two centuries of service in industrial plants as a standard corrosion-resistant material. Acid manufacture, pickling, plating, anodizing, waste acid recovery, and a host of other operations have all made use of lead's resistance to corrosive chemicals—particularly sulfuric acid and its derivatives. Although other materials have been developed to compete with lead in this field, the use of lead has continued to expand. Of course, this is due to its inherent corrosion resistance and to the growth of the chemical industries. But it is also due to the experience gained from the long and varied use of lead in this field.

Although lead is used in a variety of shapes and forms, by far the major portion of the lead used falls into three general product categories: rolled sheet, extruded pipe, and cast shapes.

Rolled Lead Products. The major part of all the lead used by industry for handling corrosive chemicals is in the form of rolled sheet products. Sheet lead weighs approximately 1 lb/sq ft for each $\frac{1}{64}$ in. of thickness, is usually specified by weight per square foot rather than thickness. For example, 4 lb lead is $\frac{1}{16}$ in. thick; 60 lb sheet is 1 in. thick. These sheet products are used for storage and reaction tanks, ducts and flues for handling corrosive fumes, and launders to convey solutions from point to point, to name a few applications. Sheets may be produced in widths up to 10 ft and in lengths up to 60 ft depending upon the thickness. Sheets 10 ft wide and 20 ft long are usually considered standard.

Extruded Pipe and Coils. Lead is extruded readily into various shapes, and large quantities of extruded lead are utilized in the plating, chemical, and related industries. Principal uses find it as pipe for conducting corrosive solutions and as cooling or heating coils submerged in corrosive chemicals. Sizes are limited only by extrusion equipment; for example, they range from fine tubing $\frac{1}{16}$-in. inside diameter and even less to 12-in. inside diameter. Almost any desired wall thickness and cross sections of practically any shape can be obtained. An advantage of lead pipe is that it is readily bent to conform to intricate design specifications. Joints may be made by welding, soldering, or by mechanical means—the choice depends upon end use. Welding or "burning" is generally used in chemical construction.

Cast Lead Products. Large quantities of lead are employed by the chemical industry in the form of castings. Lead and certain of its alloys are excellent for castings provided that high strength is not a requisite and they are not for use at temperatures higher than the melting point of the alloy. Ordinary chemical or acid lead, usually too soft for this purpose, is alloyed with antimony for strength. Lead hardened in this manner is cast into pumps and valves as well as many special shapes and fittings. Occasionally reinforcing elements made of stronger materials are cast into the lead to

TABLE 1. COMPARISON OF TENSILE STRENGTH AND CALCULATED BREAKING STRESS FOR 30-YEAR LIFE

	20°C (68°F)		60°C (140°F)	
Alloys	*Tensile Strength (psi)*	*Stress 30-year Life (psi)*	*Tensile Strength (psi)*	*Stress 30-year Life (psi)*
Pure lead	1,600	325	1,000	250
1% Sb	2,600	600	2,000	325
6% Sb	7,700	1,000	5,500	650
11% Sb	7,700	775	6,500	500

provide greater strength. Casting qualities are excellent, the melting temperatures low, and corrosion resistance is good under most conditions.

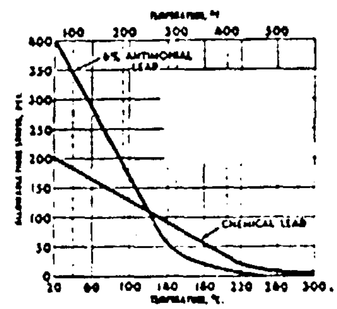

FIG. 1. Maximum allowable fiber stress in chemical and 6 per cent antimonial lead pipe at various temperatures.

Design Criteria for Lead Installation

The unique mechanical properties of lead must be considered when designing lead chemical equipment. The most important considerations are its low mechanical strength, its lack of elasticity which results in permanent deformation under stress, its tendency to creep under any sustained load, and its low fatigue limit under repeated stresses. In fact, it could be said that lead tends to act as a plastic solid rather than an elastic or rigid one. There is evidence that indicates that there is no limiting stress below which long continued steady load or continued cycling stresses will not ultimately cause failure through creep or fatigue. Fortunately, there is a practical stress level below which, with proper design and adequate support, lead construction will last indefinitely.

Mechanical Properties. The apparent tensile strength, yield point, and hardness of lead are strongly influenced by test conditions, particularly rate of application of load. The data in Table 1 illustrate this.

Both creep and fatigue properties are increased by alloying. But, the enhancing effect of alloying on creep properties is lost at high temperatures. Fatigue resistance is raised partially by the grain refining effect of alloying elements. Yet even in alloys of comparable grain size, it has been found that additions of antimony, tin, or other alloying elements increase fatigue resistance. Furthermore, the improvement persists at elevated temperatures.

Despite the low strength and plastic properties, design stress levels have been empirically established that will give indefinite service life (Fig. 1).

Consideration must also be given to the problem of adequately providing for expansion and contraction of lead. Lead has a relatively high linear coefficient of thermal expansion, that is, approximately three times that of steel; consequently provision must be made to allow for this expansion (Fig. 2).

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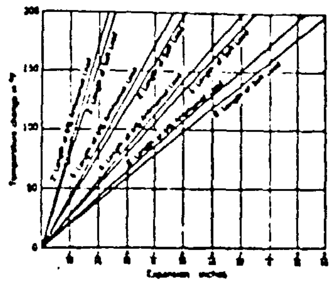

FIG. 2. Linear thermal expansion of soft lead and antimonial lead.

Sheet Lead Construction

Because of its low strength, lead is usually supported by some other stronger material such as steel, wood, or concrete. Sheet lead construction is probably the oldest method of using lead as a material of chemical construction. Basically, there are two principal methods of sheet lead construction. Cage construction consists of a lead sheet supported in a steel or wooden framework, whereas lead-lined construction consists of a lead sheet lining in a structural shell such as steel or wood. Nevertheless, there are probably as many modifications as there are applications for both types of construction.

Sheet lead construction is generally regarded as the method which requires the least capital outlay, moreover this method has additional advantages. Should repairs be necessary, they are easily made in the field, and once the vessel's useful service life has expired, the lead can be reclaimed as scrap and sold at the highest relative rate of any of the common metals.

Cage Construction. The first chambers for the manufacture of sulfuric acid were of cage construction, i.e., simply large sheet lead boxes supported by timbers. In cage construction the lead sheet chamber is supported by a basket or cage-like framework of steel or wood. Modern methods tend more towards the use of steel flats and angles welded together.

This type of construction has several advantages, however it cannot be used under conditions of high pressure or vacuum. For those applications where it can be used, it offers low material costs and usually easier assembly in the field, since handling of bulky and heavy steel sheets is eliminated.

In addition, there are other important advantages. The spacing between the framework permits leaks to be easily located and repaired from the outside in a matter of minutes. This type of open construction in which the lead is fully exposed to the atmosphere provides an extremely effective and inexpensive method for cooling liquids which are received hot or where heat is generated by reaction such as battery acid dilution. Very frequently, where the size of the vessel dictates, extra support is required which is accomplished by *strapping* with long horizontal and/or vertical steel flats or ovals to the outside of the lead sheet lining for additional support.

Cage construction allows the straps to be mounted externally. Recently designed chambers support the lead sheet walls in a special steel framework that permits a certain amount of movement of the lead with temperature changes independent of the steel frame as shown in Fig. 3.

Lead-Lined Construction. Sheet lead-lined wooden or mild steel tanks are commonly used and have been for many years. Lining thicknesses usually range between 8 and 16 lb. Occasionally two or more different thicknesses are used in the same vessel with thicker sections in the areas subject to erosion or where greater strength is required. Either existing vessels or specially constructed ones of concrete, wood or steel can be readily lined with lead to make them suitable for handling corrosive chemicals. In other words, by lining any old but structurally sound vessel with lead, it becomes unnecessary to construct an entirely new one.

Lower construction costs are realized when the sheet lead is hung from the top of a

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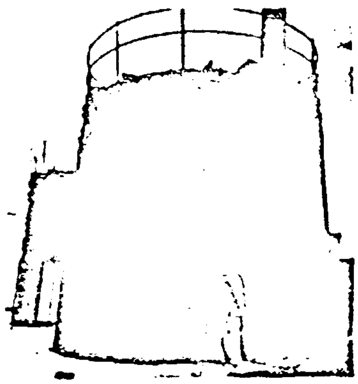

Fig. 3. Water-cooled sulfuric acid chambers constructed of sheet lead supported by a free-standing steel structure.

vessel shell, but this is confined to relatively small vessels. A variety of tank designs using hanging lead linings have given satisfactory service. A variety of support methods for deeper vessels have been developed, of which the use depends upon the tank design, size, and the proposed usage. Lead sheets can be supported on a steel or wooden shell by large cut steel washers and round head bolts as shown in Fig. 4. The cut washer distributes the load over a larger area than the bolt alone; subsequently bolt and washer are covered with a lead cap burned to the lining.

Strapping. In deep tanks, or under conditions involving fluctuating temperatures or higher stresses and vibration, a series of vertical, and sometimes horizontal, steel straps are used for support. Strapping consists essentially of supporting the lead sheet against the steel shell with flat steel bars fastened at frequent intervals inside the lead lining and through it to the outer steel shell. These straps are covered with strips of lead welded to the lead lining on either side, thus presenting a continuous, resistant lead surface to the corrosive chemicals contained.

Lead Bonded Sheath

In addition to the lead linings previously discussed, lead can be bonded directly to iron and steel for use with corrosive chemicals, particularly in high temperature processes. The thickness of the homogeneously bonded layer, depending on the use, ranges from 1/8 in. to 3/4 in. As relative motion between the two metals is constrained by the plastic flow of the lead, such linings are recommended where: (1) The reaction vessel operates under vacuum; (2) Rapid or wide temperature variations occur that would cause fatigue and stress corrosion in loose linings; (3) Good heat transfer characteristics are required; (4) High temperature operation is essential (bonded linings will not creep at temperatures up to 450°F); (5) Lightweight construction, as in tall vessels, is required; and (6) Vibration and repeated shocks are encountered.

Two methods of bonding lead linings on

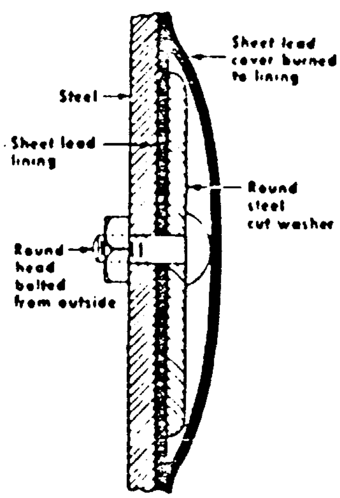

Fig. 4. Button-type fastening of sheet lead lining to steel structure.

steel are in common use; that is, burning bar and casting. The critical step in both methods is preparation of the base metal surface before bonding. The usual method is to clean the steel initially by shot blasting to expose an oxide-free surface. Pickling, usually with 10 per cent sulfuric acid, is then sometimes used. Fluxing with zinc-ammonium chloride and stannous chloride or certain proprietary fluxes is carried out just before bonding.

The oldest method of bonding lead to steel, the *burning bar method*, is particularly useful for small areas and irregular shapes. In this hand operation, lead is applied to the prepared surface by melting from a "burning bar" using a manual burning torch. A skilled operator can check the bond before continuing to cover the surface with a layer of lead about 1/8 in. thick.

Casting. The second method of bonding lead to steel is efficient and relatively inexpensive. After the steel has been cleaned and fluxed, molten lead is carefully poured on the surface. After cooling, the steel-lead plate is often rolled in a conventional rolling mill to reduce grain size and to increase density. The plate is subsequently formed into the desired shape.

Sprayed Coatings. Lead coatings also may be applied by spraying. Lead wire is fed into a spray gun which melts the metal and blows it onto the surface to be coated. Since there is no chemical bond between the lead and base metal, the latter is first sand-blasted or otherwise roughened and cleaned to provide good mechanical anchorage for the coating. Pinholes may be minimized by peening the surface after coating.

Lead Acid-Brick Construction

An important method of chemical construction which has been devised to resist the most severe conditions encountered such as the handling of corrosive slurries and high operating temperatures has led to the development of lead acid-brick construction —a lead-lined steel shell with an acid-brick inner lining (Fig. 5). This type of construction has proved effective in a large number of installations where lead alone or other materials of chemical construction have been inadequate. When properly designed and installed, they will perform admirably under the most severe conditions.

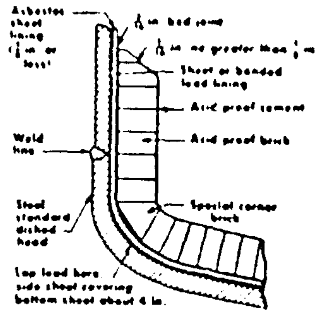

Fig. 5 Acid-brick lining with impervious lead interliner for chemical tanks.

Brick linings have excellent corrosion resistance but cannot be used alone because they are essentially permeable materials. In fact, the best grades of acid-proof brick are intentionally made 3 to 4 per cent porous for thermal shock resistance. The lead lining, therefore, acts as a membrane between the shell and the brick lining so that any liquid that penetrates the brick work will be contained by the lead.

The special conditions which warrant the selection of lead acid-brick construction are discussed below.

High Temperatures. Referring to temperatures beyond the mechanical limitations of lead, the brick lining provides an insulating layer resulting in a temperature gradient. Consequently, although the temperature within the vessel at the lining may be anywhere from 300 to 1300°F, the temperature of the lead membrane is well within its mechanical limits. The upper temperature limitation of this type of construction is merely a function of the thickness and thermal insulation properties of the brick lining. For example, there are quite a few applications for sulfuric acid-sulfur dioxide scrubbing operations with entering temperatures ranging as high as 1000°C.

High Pressure or Vacuum. Certain acid recovery units are brick- and lead-lined and operate under vacuums as low as 0.25 in. of mercury at about 250°F. Under these conditions, the brick lining affords a uniform support under static or cyclic conditions of vacuum and pressure which would normally cause a great deal of undesirable movement of the lead lining.

Abrasion and Erosion. Many vessels use methods of agitation such as steam jet lances, which would cause serious erosion of an unprotected lead lining. A brick lining protects the lead membrane from the strong scouring effect of the agitators or from any other abrasive condition that may be present such as the presence of abrasive slurries. In addition, pickling tanks holding sulfuric acid mixtures are frequently lead-brick lined to eliminate the possibility of damage due to careless handling of the objects being pickled.

Thermal Insulation. In addition to allowing ambient vessel temperature well above the temperature limits of the lead membrane, a brick lining is desirable in the operation of vessels with rapid time-temperature fluctuations in the lead lining, thereby reducing markedly the tendency for thermal fatigue in the lead.

Severe Corrosion Conditions. In certain cases, the presence of the brick layer deters "drilling" and "scabbing" type attack which occurs when lead is exposed to the direct action of combinations of sulfuric acid and certain organic chemicals. Such attack, for example, occurred in a vessel which contained 35 per cent sulfuric acid plus coal tars at 120°F. A comparison of corroded pieces with pieces which were protected by a 4½-in. course of hard-burned high silica acid-resisting brick and backed with acid-proof cement, demonstrated the effectiveness of the lead acid-brick construction in this application.

In general, whether or not an organic material will attack lead in combination with sulfuric acid apparently is related to the materials' polarity or lack of it. Nonpolar substances such as gasoline, benzene, and toluene are not corrosive to lead. Evidently the assistance provided by the acid-brick lining is to restrict the penetration of the polar substances to the lead lining. The nonpolar materials, interestingly, penetrate acid-brick very rapidly; nevertheless, they are harmless.

Lead Pipe and Coil

Lead is extruded readily into various shapes, and large quantities of extruded lead pipe are used in the building, chemical, and related industries, principally as pipe for conducting corrosive solutions and as cooling or heating coils submerged in a corrosive medium.

One of the great advantages of lead piping, in addition to its corrosion resistance, is its adaptability and the facility with which it can be installed. When pipe bends are required, straight pipe may be filled and packed with sand, and bent. During the operation, the outer wall becomes thinner; moreover if the radius of the bend is less than four times the inside diameter of the pipe, this outer wall or "heel" is reinforced by "burning on" an added layer of lead. Shorter radius bends may be made by means of mitred joints between short sections of pipe. Alternatively, a variety of pipe fittings may be purchased as stock items, cast in chemical lead or antimonial lead. These are supplied in four forms:

(1) With solid lead flanges welded in place.

(2) With cast iron or steel slip-on flanges.

(3) With over-length for flanging in the field.

(4) With plain ends for welding.

Horizontal runs of lead or lead alloy pipe are generally continuously supported

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in steel or wooden troughs or in specially constructed sheet metal shells. Vertical runs are supported at frequent intervals such as every 18 in. Long runs are provided with expansion bends if they operate at high or fluctuating temperatures.

This traditional method of supporting pipe has the disadvantages that any leakage may cause damage to the supports. Free expansion and contraction are hindered, and the location of any leak is not always evident or easily accessible for repair.

Thickness of lead pipe depends on several factors, including corrosive attack, abrasion, and pressure to be handled; for example, if wall thickness is calculated in the usual manner to accommoda[illegible] a given pressure, additional wall thickness is allowed to compensate for loss through corrosion or abrasion. The velocity at which a corrosive solution flows across the surface of lead is an important factor in the rate of corrosion, but it is difficult to establish a definite relationship between the two. As an illustration, Table 2 shows the effect of increasing the velocity of a 20 per cent sulfuric acid solution at 25°C (75°F) across the surface of lead:

TABLE 2

Velocity of Solution Across Lead Surface	*Rate of Corrosion in/month × 10⁻⁸*
8.6	55
97	17
155	16
300	86

The erosion of lead pipe may be retarded by designing the system to reduce flow rate friction as much as possible, e.g., eliminate short 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.

One of the more interesting lead coil developments is a heat exchanger consisting of two lead pipes, one within the other. The larger pipe has a 2-in. inside diameter with $\frac{1}{4}$ in. wall and is extruded from 6 per cent antimonial lead. The inside pipe made of soft lead is 1 in. in diameter with a $\frac{1}{4}$-in. wall at the thin portion. The exterior of the inner pipe has been extruded in the shape of a six-pointed star to provide extra support and also to retain concentricity.

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 using steam is difficult or hazardous or where electricity is inexpensive.

Bonded and Lead Covered Pipe. Under conditions of high temperature or excessively high pressure where greatest strength is essential, lead-lined steel or cast iron pipe or, possibly, lead-covered copper pipe may be used. Bonding techniques similar to those described earlier are utilized in the manufacture of these products.

In making bonded lead pipe a length of steel is first cleaned and fluxed. Then molten lead is cast on in sections by rotating the pipe. A second method uses instead of molten lead a length of extruded lead pipe which is inserted inside a properly prepared pipe of steel. The ends of the lead pipe are sealed and steam pressure applied to expand it against the outer pipe. Pressure is raised until the temperature reaches the point where bonding occurs between the lead and steel, aided by pre-tinning the steel with a thin solder film. In this way, the lead is said to be "sweated" to the steel pipe.

Inspecting and Testing Lead Linings

Lead-protected chemical-processing vessels are normally inspected for the presence of pinholes or porosity in welded seams on sheet-lead linings, hairline cracks, either in the weld or the sheet, resulting from fatigue or stress corrosion; and pinholes, inclusions, or bond discontinuities in the case of clad

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vessels. Defects falling into any of the above classifications, although they may not penetrate the lining completely, do form a potential trouble spot that may shorten the lining's expected life—a problem that can be minimized through the use of proper inspection and testing.

Testing Sheet-Lead Linings. After the completion of a new installation or extensive repairs on an old lining all the welded (burned) seams are carefully checked visually by the lead burner and all obvious defects corrected. If it is necessary to check the soundness of a lead weld such as on butt joints to determine the depth of fusion, a section of the seam can be trepanned with a trepanning drill to obtain a cross section. On a bonded lining, this technique has also been used to check the nature of the bond and the thickness of the lining. In either case, however, the test is destructive, whereas radiographic techniques provide a more effective, nondestructive test for weld soundness. For closer and more exacting examination of welds, a fluorescent or dye penetrant that is drawn into tiny cracks or pores by capillary action is often used. After the excess is cleaned off, the chemical remaining in the imperfections can be developed or brought to the surface, where it may readily be identified, either by a bright glow under ultraviolet light, in the case of the fluorescent penetrant, or by a distinctive color, in the case of the dye penetrant.

Interpretation of each indication is all important. Practically all procedures involving the fabrication of lead result in the possibility of confusion between a defect and a simple surface marking; therefore, it must be realized that a high degree of discernment must exist to differentiate between a true defect and a harmless surface irregularity.

Testing Bonded Linings

Acid-wash tests have been accepted as a standard inspection technique on bonded lead-lined vessels for the detection of pinhole penetration, surface imperfections, and porosity. It will not detect subsurface flaws. First, the entire lead surface must be cleaned free of any oil or grease films. Then, a dilute solution of hydrochloric acid (5 to 15 per cent acid) is freely applied to the entire surface by brushing or swabbing and is allowed to remain for 12 to 24 hr. Before the acid is cleaned off, the lead surface may be examined by an inspector for wet spots or discoloration, or, better still, the acid washed off with water, and the surface allowed to dry and then be examined. A wet spot indicates either surface porosity or a pinhole that has not penetrated the lead. Rusty discoloration indicates a pinhole that has penetrated through to the steel. Repairs are usually made on the wet spots by touching up with a lead burner's torch. Rust-spot areas are removed and the steel cleaned so that new lead can be bonded. After all rust-spot indications have been rebonded, the acid-wash test is repeated to give a final check.

A second method is the same test in principle, but it is more effective and is restricted to lead-clad pressure vessels. The vessel is heated by internal steam pressure to about 500°F until thermal equilibrium is reached. At this point, the steam is turned off and pressure rapidly released from the vessel. Air is subsequently admitted and the vessel is cooled and inspected for bubbles. If none are found, the test is repeated. After the second cycle, if none are found, the lining is accepted as 100 per cent bonded.

Ultrasonic tests involving the transmission and reflection of ultrasonic waves lend themselves well to the location of unbonded areas and subsurface inclusions and can also provide a simple nondestructive means for determining the lead thickness in bonded linings. Two basic methods of ultrasonic inspection have been used successfully on bonded lead linings: the resonance method, and the pulse or echo method.

In the resonance method, the crystal head on the instrument transmits an ultrasonic wave into the metal and the waves reflected from the opposite surface are detected au-

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dibly in headphones or visibly on a calibrated cathode-ray tube or a dial reading. When lead is well bonded to steel, the waves are not reflected from the steel-lead interface; consequently no signal is obtained. Small unbonded areas, one half of the crystal-head size or smaller, or semibonded areas, may result in partial reflection of the waves from the interface, indicated by weak signals. Strong signals reveal a complete lack of bond, larger in area than the crystal head, whose outline can be easily traced with the instrument.

In the pulse or echo method, vibrations are sent out through a similar crystal head. The pulse travels through the metal until it strikes a flaw and is reflected, whereas the rest of the waves travel on until they hit the opposite surface and are reflected. Although the vibrations are alternately off, the crystal detects the reflected pulses and the time difference is converted electronically to readable indications of depth on a cathode-ray tube.

Radiographic Testing. Although, because of its high density, lead is normally used as a material for shielding against radiation, it is possible with the higher radiation energies commercially available today to obtain practical radiographs of the load in lead-lined steel vessels, to locate entrapped gases and subsurface foreign inclusions not detectable by acid-wash methods.

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