Coatings and Linings for Secondary Chemical Containment in Power Plants

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Environmental contamination by toxic and dangerous chemicals has become an important concern in recent years. Acid rain, lead contamination, asbestos, incidents such as the tragedies in Bhopal and Love Canal, groundwater contamination in Silicon Valley, and the Alaskan oil spill have increased everyone’s awareness of the hazards of industrial chemicals.

Protection of the environment and the population from dangerous chemicals has led to the passage of much legislation and has placed considerable liability on the chemical user. Users of toxic and dangerous chemicals must take precautions to prevent the inadvertent release of these chemicals into the environment.

Few industrial facilities use no toxic materials. One industry that is not generally considered a user of toxic materials is electric power generation. Electric generating facilities do, however, make use of numerous chemicals that are essential to operation. Diesel or fuel oil is stored for use as the primary fuel or for emergency back-up. Sodium hydroxide, sodium hypochlorite, and sulfuric acid are used in water treatment and are processed by the neutralization system.

Proper design, engineering, construction, and maintenance of primary storage vessels and transport systems can go a long way in preventing leaks and spills, but accidents happen. Threaded connections leak, gaskets and seals fail, construction materials corrode and age, and deviations from the prescribed operation can occur. Unexpected malfunctions like these result in leaks and spills.

When leaks and spills happen, there must be plans for preventing chemical release to the environment. The most effective and reliable means of preventing chemical release is secondary chemical containment.

A secondary chemical containment is intended to catch and contain leaks and spills from the primary storage vessels and transport systems until the toxic materials can be neutralized and permanently disposed of. Secondary containment is a back-up system that only functions when there is an inadvertent chemical leak or spill. Chemical exposure is anticipated to be infrequent and short term, not continuous exposure like the primary system. Even though secondary containment structures do not require the same level of sophistication as the primary systems, chemical exposure is a very important design consideration. Sec-
Secondary containments must provide a high degree of chemical resistance and impermeability but do not have to equal that of the primary system.

### Design Considerations

Material selection for secondary containment should be based on a review of the following factors.
- Degree of reliability needed
- Toxic or hazard potential of a chemical spill
- Potential for leaks and spills
- Specific chemical exposure and concentrations
- Operating and environmental temperatures
- Exposure duration, detection, and clean-up plans
- Design life
- Traffic and physical exposure during normal operation

The first consideration is to assess the danger and potential liability presented by an inadvertent chemical release and determine the degree of reliability needed. Extremely toxic and dangerous chemicals will dictate a high degree of reliability.

The secondary containment may have to equal the primary vessel in terms of chemical resistance and impermeability.

With less dangerous chemicals, a small amount of release may be tolerable, permitting a lower degree of reliability from the secondary containment.

New state and federal regulations also dictate some design requirements. Increased reliability almost always increases cost, and these factors must be balanced.

### Concrete Containment Structures

Secondary containment can include double-walled vessels, a pipe within a pipe, plastic membrane liners, fiber-reinforced plastic pans, or polymer concrete. However, cement-based concrete is most often selected as the principal construction material because of its favorable cost, strength, and ease of construction. Concrete spillways, pads, pits, sumps, and vaults are common secondary containment structures.
However, concrete alone is insufficient in many chemical environments (Fig. 1). The American Concrete Institute’s Guide, ACI 515.1R, includes a listing of chemicals and their effects on concrete. Acids and caustic solutions can disintegrate concrete rapidly. Liquids can permeate into concrete, corroding steel reinforcement. Concrete is also subject to cracking, and these cracks are pathways for a liquid to contaminate the environment. Therefore, when concrete is used in construction of secondary containment, it must be coated or lined to provide reduced permeability and increased chemical resistance.

Coatings are the most economical means of increasing the protection provided by concrete secondary containment and are the main topic of this discussion. Other materials will be discussed briefly.

Concrete possesses a number of physical characteristics that influence the reliability and, hence, the selection of a coating or lining. Concrete is not uniform, and its surface condition can vary considerably. The surface of a concrete structure may be flat, smooth, and free of holes; it may be rough with large holes, honeycomb, fins, ridges, and sharp protrusions; or the surface may be anywhere in between.

In addition to surface finish, concrete properties can vary due to composition and installation differences. The tensile strength of the concrete may not be sufficient to resist stresses exerted by some coatings.

Concrete structures are also subject to cracking. Shrinkage cracks may develop during cure, and stress cracks may develop later due to expansion and contraction, settling, or other movement. Construction and expansion joints may also present a major challenge and must be considered during material selection (Fig. 2).

Whether the concrete structure is existing or being planned is also a major consideration. Existing structures have already cracked as much as they are likely to, so that once these cracks are repaired, further crack development is not a big concern.

When evaluating existing cracks, one must determine whether they are moving or fixed. Fixed cracks can simply be filled or bridged if they are small enough. Moving cracks may have to be treated as expansion joints. Existing concrete structures may already have construction or expansion joints that must be specially treated. Existing concrete structures may have also been exposed to chemical leaks and spills requiring special cleaning techniques, neutralization, and possible concrete repair.

When selecting a coating for a planned structure, the development of cracks is a much more serious consideration. However, design and installation can be more tightly controlled to better accommodate the coating. When a concrete structure is being planned, surface finish can be specified, and expansion and construction joints can be minimized or avoided.

### Coatings for Concrete Secondary Containment

Liquid-applied coatings used for secondary containment are based on epoxy, epoxy novolac urethane, polyester, vinyl ester, vinyl ester epoxy novolac, bisphenol fumarate, furan, and other resins. They are available in the following types of systems.

- Thick, cloth- or mat-reinforced systems
- Moderately thick, trowel-, roller-, and spray-applied flake- and fiber-filled systems
- Thin film, conventional, and thicker unreinforced, spray-applied coatings

Frequently, a coating that suffers some attack by exposure to the spilled chemical can be used for secondary containment, avoiding the use of far more expensive systems. The attack on the
Coatings for Secondary Containment

coating must be gradual enough to allow ample time for clean-up before the coating is penetrated. If such an approach is taken, its success hinges on the commitment to detect and clean up leaks and spills quickly and to maintain the coating in good condition, free of cracks and voids. If the chemical disintegrates concrete, a fault in the coating could result in the need to repair the concrete itself or allow the chemical to leak into the ground. The coating may actually mask this problem. For instance, the chemical could seep through the fault and undercut the concrete below the lining.

In the event of a spill or leak, repairs may be needed to the coating to restore the original degree of protection. However, coating repairs are easier and less expensive than removing and replacing deteriorated and contaminated concrete, and the primary goals of containing the chemical and protecting the environment can be achieved. Chemical attack to the coating is a major consideration in the type and thickness of the coating selected.

In many situations, the secondary containment must be suitable for more than 1 chemical. These chemicals are often widely varied so that the same containment must handle acids, bases, and solvents. This complicates material selection considerably. During selection of a coating for concrete, compromises must be made to provide adequate resistance to all of the chemicals.

Reinforced Coatings

The thick cloth- or mat-reinforced systems should be considered where the chemical will rapidly attack concrete or where a high degree of reliability is needed from a coating because of the chemical’s hazard potential. These thick film systems (typically 1/8 in. [3.2 mm]) are reinforced with 1 or more layers of glass or synthetic fiber mat or cloth.

For services where glass is attacked by chemicals such as concentrated mineral acids and caustic, synthetic fiber mat or cloth is used in lieu of glass. For added chemical resistance, a resin-rich topcoat may be included. Heavy woven roving- and multilayer cloth-reinforced systems offer the best performance.

Thinner (1/16 in. [1.6 mm]) systems with one layer of lighter mat are also available, reducing cost. By virtue of their thickness and continuous reinforcement, these systems provide the best protection of the liquid-applied systems available. The thickness of the coating and application by trowel or roller allow these materials to be applied to a rougher surface than other coatings and make them less prone to pinholes. The continuous reinforcement helps the coating materials bridge small, fixed cracks and mitigate the adverse effects of concrete cracks and movement.

Resin selection should be based on chemical resistance. Epoxies, polyesters, and vinyl esters are common; epoxy novolacs are starting to become commercially available.

These heavy, reinforced coatings are the only concrete coating systems capable of handling extremely aggressive chemicals, such as 93 percent to 98 percent sulfuric acid. Although these coatings may offer only moderate resistance to some aggressive chemicals, they can be relied upon to provide short-term protection from intermittent exposure by virtue of their heavy thickness. They are frequently used because of their favorable economics.

The chemical must first penetrate 1/8 in. (3.2 mm) of coating, allowing time for clean-up or dilution before the chemical reaches the concrete substrate. Seventy-two hours before coating penetration is usually the minimum length of protection required. Reinforced coatings are the most chemical-resistant of the liquid-applied materials available. To get better chemical resistance, one must use thermoplastic sheet or masonry linings to protect the concrete.
Flake- and Fiber-Filled Coatings

Where a lesser degree of reliability is sufficient, such as when the chemical is not aggressive to concrete, less expensive, thinner flake- or fiber-filled coatings may be used. These coatings offer reasonable protection against ground contamination, and the concrete itself offers significant containment because permeation would take some time as long as the concrete is not cracked.

The moderately thick fiber- or glass flake-filled systems offer chemical resistance comparable to that of the 1/8 in. (3.2 mm) reinforced systems because the same base resins are used. However, these systems are generally only 40 to 80 mils (1.0 to 2.0 mm) thick and do not contain a continuous reinforcement. Consequently, they are not equivalent to the heavier systems, so they will have less resistance to crack propagation and a lower degree of reliability against chemical release. The troweled-on versions of these coating systems offer somewhat better resistance to chemical permeation than spray-applied versions of the same resin because the act of troweling tends to orient the flakes and fibers into a denser configuration than the random orientation achieved by spray. Troweling also forces material into concrete surface defects, providing a reduced occurrence of pinholes and requiring less stringent surface preparation than is needed by the non-troweled, thinner coatings.

These thinner, unreinforced systems are only recommended for intermittent, short-term chemical exposure because cracks are quite possible, making periodic repairs necessary. This periodic repair is not practical in prolonged chemical exposure or immersion service because damage is not readily accessible, and considerable exposure of the concrete to the chemicals could occur.

Unreinforced Coatings

Thin film epoxy, vinyl, chlorinated rubber, and urethane coatings have also been used on concrete. These systems are usually spray-applied in 1 or more coats to achieve a total film thickness of 10 mils (250 microns) or more. These systems resist a fair range of chemicals and offer attractive economics due to the labor savings of spray application and the reduced amount of material needed.

However, thin film coatings also provide the shortest service life and will readily crack with the concrete. These coatings are recommended only for protection from occasional splash and spillage of chemicals that are not aggressive to concrete. In addition, they are recommended only where they can be easily monitored and readily repaired and maintained. They are also useful in coating walls where easy clean-up or sanitation is required.

The epoxy, polyester, and vinyl ester resins are rigid and brittle. They will accommodate very little movement without cracking. For this reason, particular attention must be paid to expansion joints and existing, moving cracks. The coating manufacturer should be required to provide details on how these areas should be treated.

Power Plant Examples

Examples of coated secondary containment structures follow. The coated containment structures were engineered for use in the water treatment systems and diesel fuel storage areas of 4 power plants. The examples will illustrate the considerations and selection process involved in choosing a coating for concrete secondary containment. Table 1 summarizes the examples.
Sulfuric Acid
The 4 plants used 98 percent sulfuric acid in their water treatment systems. The storage tank was placed in a concrete secondary containment structure large enough to contain all of the tank's contents. Concentrated sulfuric acid will rapidly disintegrate concrete and corrode steel reinforcement. It is also very dangerous and must be contained.

Concrete alone was inadequate. Because of the hazards posed by concentrated sulfuric acid and its ability to destroy concrete, a high degree of reliability was essential. For a high and economical degree of reliability, a 1/8 in. (3.2 mm) thick, woven roving-reinforced vinyl ester coating was selected. The vinyl ester offered the best resistance to concentrated sulfuric acid, but it was not inert.

Vinyl ester coatings will be attacked by spills of concentrated sulfuric acid, so the heavy thickness of the reinforced systems is needed to provide the minimum 72 hours of protection required at those plants. The woven roving reinforcement also offered the highest degree of crack propagation resistance available in a coating.

At one facility, a leak did occur during the first year of service. This leak went undetected for an indefinite time, and the topcoat of the coating was destroyed in a six-foot-square (5.4-square-meter) area, but the concrete was protected, and no chemical release to the environment occurred.

Laboratory testing indicates that the new epoxy novolac resins may provide better resistance to concentrated sulfuric acid than the vinyl esters, but epoxy novolacs are just becoming commercially available. Thus, long-term case histories showing successful application are not yet available.

Sodium Hydroxide
A 50 percent concentration of sodium hydroxide is also used in water treatment, and a concrete containment was constructed for the tank storing the sodium hydroxide. Fifty percent sodium hydroxide is aggressive to concrete, but attack is much slower than it is with sulfuric acid. Sodium hydroxide is also a dangerous chemical, so for high reliability, a reinforced system was specified. For minimization of the number of products on site, the same vinyl ester coating used on the sulfuric acid containment was specified here. The vinyl ester provided suitable chemical resistance for 72 hours of containment, but a heavy, reinforced epoxy system would offer better chemical resistance.

In 1 plant, the acid and caustic storage tanks shared the same 10-foot (three-meter) x 20-foot (six-meter) concrete secondary containment structure (Fig. 3). This structure had been in service for several years but had been left bare. Since it was an existing and fairly small structure, the future development of cracks was not likely; thus, an unreinforced, 60-mil (1.5 mm) thick coating was selected. For chemical resistance, a highly cross linked, epoxy novolac, resin-based coating was used.

Neutralization Process
In the neutralization system, both the 98 percent sulfuric acid and the 50 percent sodium hydroxide solution are fed to the same tank. A concrete containment structure large enough to contain 100 percent of the content of the neutralization tank was constructed. Because the rupture of a feed pipe could result in a spill of 98 percent sulfuric acid or 50 percent sodium hydroxide, the coating had to be capable of resisting both solutions. For the reasons previously discussed, the heavy, reinforced vinyl ester system was specified here. The epoxy would have been somewhat better for the sodium hydroxide but would not handle the acid. Epoxy novolacs may prove to be very good here.

In 1 case, a high-build coal tar epoxy system was selected for a concrete containment around a neutralization tank. A reinforced vinyl ester coating had been recommended, but a closer look at the application indicated that the acid and caustic would be diluted, and the containment would be exposed only to a solution ranging in pH from 4 to 12. These conclusions were based on experience with the existing structure. The particular coal tar epoxy selected had actually been successfully tested by the Sanitation District of Los Angeles County.\(^2\)

Sodium Hypochlorite
In addition to sulfuric acid and sodium hydroxide, a 15 percent solution of sodium hypochlorite is used in the water treatment system. Fifteen percent sodium hypochlorite can be very harmful to people and aggressive to organic materials, but it is not particularly corrosive to concrete, disintegrating it slowly. Since concrete possesses some chemical resistance to sodium hypochlorite, the structure itself will provide containment as long as it is free of cracks. However, a 40-mil (1.0-millimeter), glass flake-filled vinyl ester coating was specified to improve the structure's performance and avoid concrete repair. This coating system offers good reliability but must be checked periodically to make sure it has not cracked.

Diesel Fuel
No. 2 diesel fuel is stored at these plants for the back-up emergency generators. The storage tanks are installed in a concrete containment structure.
No. 2 diesel fuel is not aggressive to concrete but must be contained since it can contaminate ground water and is a serious fire hazard. Diesel fuel can permeate bare, porous concrete, so it was coated to increase its impermeability. Since the concrete itself offers good containment, a thin film, unreinforced coating is sufficient. An epoxy was specified because it resists diesel fuel.

**Table 1 Proposed Coatings for Concrete Secondary Containments**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type and Concentration of Liquid</th>
<th>Description of Coating</th>
<th>Concentration</th>
<th>Exposure</th>
<th>Temperature F (°C)</th>
<th>Maximum Temperature of Coating in General Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid storage tank</td>
<td>98% sulfuric acid (H₂SO₄)</td>
<td>1/8 in., glass cloth-reinforced vinyl ester</td>
<td>80-98%</td>
<td>Immersion</td>
<td>160 (71)</td>
<td>160 (71) 250 (121)</td>
</tr>
<tr>
<td>Caustic storage tank</td>
<td>50% sodium hydroxide (NaOH)</td>
<td>40-mil, flake-filled vinyl ester</td>
<td>50%</td>
<td>Immersion</td>
<td>130 (54)</td>
<td>130 (54) 200 (93)</td>
</tr>
<tr>
<td>Combination acid/ caustic storage tanks</td>
<td>98% sulfuric acid 50% sodium hydroxide</td>
<td>60 mil epoxy novolac 98% H₂SO₄ 50% NaOH Spillage</td>
<td>130 (54)</td>
<td></td>
<td>130 (54) 130 (64)</td>
<td></td>
</tr>
<tr>
<td>Sodium hypochlorite tank</td>
<td>15% sodium hypochlorite (NaOCl)</td>
<td>40-mil, flake-filled vinyl ester</td>
<td>17%</td>
<td>Spillage</td>
<td>100 (38)</td>
<td>130 (54) 200 (93)</td>
</tr>
<tr>
<td>Neutralization* basin</td>
<td>2-20% sulfuric acid or sodium hydroxide</td>
<td>40-mil, flake-filled vinyl ester epoxy novolac or 1/8-inch, glass cloth-reinforced vinyl ester</td>
<td>2-20% H₂SO₄ 50% NaOH Spillage Immersion</td>
<td>130 (54)</td>
<td>130 (54)</td>
<td>130 (54) 200 (93)</td>
</tr>
<tr>
<td>Demineralizer tank</td>
<td>2-20% sulfuric acid or sodium hydroxide</td>
<td>40-mil, flake-filled vinyl ester</td>
<td>2-20% H₂SO₄ 50% NaOH Spillage Immersion</td>
<td>130 (54)</td>
<td>130 (54)</td>
<td>130 (54) 200 (93)</td>
</tr>
<tr>
<td>Steam turbine lube oil area</td>
<td>Lubricating oil</td>
<td>40-mil, flake-filled vinyl ester</td>
<td>Crude Mineral Gasoline</td>
<td>Immersion Immersion</td>
<td>100 (38) 100 (38)</td>
<td>130 (54) 200 (93)</td>
</tr>
<tr>
<td>Boiler chemical feed area</td>
<td>5-10% phosphate, 2-5% cyclohexylamine, 1-5% isoascorbic acid</td>
<td>40-mil, flake-filled vinyl ester</td>
<td>No published data or specific test data</td>
<td></td>
<td>130 (54)</td>
<td>200 (93)</td>
</tr>
<tr>
<td>Diesel fuel storage tank</td>
<td>Diesel fuel</td>
<td>two-coat epoxy</td>
<td>Diesel</td>
<td>Immersion</td>
<td>100 (38)</td>
<td></td>
</tr>
</tbody>
</table>

* If acid content is below 5 percent maximum, a high-build coal tar epoxy system may be used.

1/8 in. = 3.2 mm; 40 mil = 1 mm

1 Derived primarily from information supplied by manufacturers.

2 Derived primarily from information supplied by manufacturers.

**Other Materials**

In addition to the coated concrete structures discussed, other materials are also used for secondary chemical containment. In many instances, one of these other materials would be preferable to coatings due to chemical resistance, temperature, physical exposure, size, or other consideration. Materials such as plastic membranes, FRP pans, polymer concrete, and masonry all have their place in secondary containment.

**Plastic Membranes and Sheet Liners**

Plastic membrane liners are available for secondary chemical containments. They offer excellent chemical resistance and impermeability. Polyethylene (PE), hypalon (chlorosulfonated polyethylene; CSPE), and polyvinylchloride (PVC) can be used to line concrete and steel sumps. They can also be applied directly over earth.
They can be fabricated into sheets of considerable size for pond liners, land fills, dumps, and other large surfaces. They are also used as the secondary containment under large aboveground tanks and around buried tanks.

A variety of thermoplastic liners are available for lining concrete structures. The most common are PVC, chlorinated polyvinylchloride (CPVC), PE, polypropylene (PP), fluorinated ethylene propylene (FEP), polyvinylidene fluoride (PVDF), and ethylene-chlorotrifluoroethylene (ECTFE). Thermoplastic sheets can be extruded over a wide range of thicknesses but are generally between 60 and 200 mils (1.5 and 5.0 mm) thick for lining applications.

These sheet linings are mechanically fastened or adhesive-bonded to the finished concrete, or they are incorporated into the concrete when it is poured. Thermoplastic liners offer a much higher degree of reliability than coatings. The fluoropolymers have near universal resistance to chemical attack. These liners are suitable for continuous immersion service in most chemicals. The fluoropolymers also possess the highest temperature resistance of the presently available sheet linings. Some fluoropolymers will handle continuous temperature exposures in excess of 400 F (204 C) with intermittent short-term exposures of 500 F to 600 F (260 C to 316 C). However, for most applications in a power plant, the less expensive to 600 F (260 C to 316 C). However, for most applications in a power plant, the less expensive

Polymer Concrete
Polymer cements are aggregate-filled resins such as epoxies, polyesters, vinyl esters, and furan. They are used like concrete as a structural material with inherent chemical resistance. Furan and epoxy novacol polymer concrete has been used in lieu of acid brick in secondary containment structures (Fig. 4).

Fiber-Reinforced Plastic
Fiber-reinforced plastic pans are usually made of polyester and vinyl ester resins. They are self-supporting. They are placed under the primary vessel. They are generally small and are used under batteries or parked electric vehicles such as forklifts. One manufacturer has a system for lining around railroad tracks where tank cars containing chemicals are loaded and unloaded.

Chemical-Resistant Masonry
Chemical-resistant masonry linings are sometimes used over concrete structures. Chemical-resistant masonry includes brick or tile systems installed with an appropriate mortar and may include an organic membrane. Masonry linings offer excellent resistance to severe chemical exposure, thermal extremes, and mechanical abrasion and wear. However, they are mostly used for primary corrosion protection rather than secondary containment because of their high cost.

Brick liners in conjunction with organic membranes are generally used where prolonged or continuous chemical exposure is combined with high temperatures and/or abrasive service such as trenches, spillways, and sumps.

The brick itself has very good temperature resistance and resists attack by most chemicals. However, brick is permeable, so, eventually, the chemical will penetrate to the substrate. A properly selected organic membrane will provide a barrier to prevent the chemical from attacking the concrete, but most membrane material is not suitable for exposure to elevated temperatures. When brick and membrane material are used in conjunction, the brick provides thermal and mechanical protection to the membrane so that the membrane can provide chemical protection to the concrete. Several tiers of brick may be necessary, depending on the temperature of the chemical and the temperature resistance of the membrane.

Brick liners are commonly used in hot acid tanks such as those used in pickling lines.

Summary
Chemical release to the environment is no longer tolerable. Provisions must be made to protect against inadvertent leaks and spills. This article has introduced typical methods of providing secondary containment, particularly coated concrete structures. The article has also highlighted the most important considerations for selecting secondary containment and how they interrelate.

References