Tanks and Liners: Is Conventional Wisdom or Reliance on Internet-Based Answers Putting your Company at Risk?

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Finishing companies face an array of unprecedented challenges. Decision-making is affected by these pressures. Conventional wisdom and/or the reliance on internet-based answers can lead to procurements that create unnecessary downtime, safety risks and loss. Factors compounding the pain of inadequate options and poor choices are aging plants and equipment, a shrinking manufacturing workforce and legal/policy/regulatory costs. Topics covered in this article include: (1) an overview of tanks and liners, (2) the true costs of downtime, (3) results from a recent tank and liner market survey, (4) the plastic paradox (including fires), (5) spark testing and leak monitoring technologies, (6) drop-ins, (7) what to look for from a supplier and (8) new advancements.

Introduction

The greatest threats facing the finishing industry today are (1) aging plants and equipment, (2) workforce changes, (3) legal and regulatory costs, and (4) faulty decision-making models.

Almost 75% of U.S. plants are over 20 years old.[1] As equipment ages, downtime increases. The true cost of downtime is more than just lost production. In addition to equipment repair costs, other factors include start-up costs, direct and indirect labor, benefits and overhead costs, bottleneck costs downstream, late deliveries, lost orders, broken promises and damaged customer relationships.

Without a good handle on the true cost of downtime, decisions are flawed. Most factories lose 5 to 20% of production capacity from downtime. Eighty percent of plants can't estimate the cost of downtime accurately. Many underestimate by 200 to 300%. Without accurate numbers, how do you know you are making the right repair or replace decisions? Could downtime be avoided?

Maintenance is a controllable expense, but only if you are proactive. Research puts maintenance costs at 9-30% of the cost of goods sold at a typical process plant, and 4-8% per year of the replacement value of the process plant itself.

Manpower is a concern in that projections show continued erosion in the manufacturing sector. Turnover is expensive whether it is management or hourly. Turnover rates continue to exceed 70% annually in most segments. It costs $4,000 to $6,000 to replace a typical minimum wage employee.

By 2012, 28% of the current workforce will retire. Over 50% of engineers will retire by 2018. Estimates indicate 25 to 54% of CEOs will be leaving within the next five years. Yet, at least half of companies have no succession plan. Departing CEOs tend to underinvest in the future of the company and are not inclined to take risks.

Legal and regulatory matters are another aspect. Costs due to factors such as corporate taxes, employee benefits, tort costs, energy costs and pollution abatement continue to rise. The gap in our competitiveness is increasing. The burden on U.S. manufacturers is over twice that of other industrialized nations. Litigation is a significant cost.

The EPA Pollution Prevention Model has shifted to put the focus on source reduction. As cumbersome as this is, still more regulation is coming. Under current law, the EPA has had to prove that a substance was a risk before it could be banned. Increasingly regulations are moving toward the European standard requiring more testing to prove a substance is safe.

Faulty decision-making plays a role. Too many focus solely on the initial cost, but overlook the added cost of premature failure. Leaks in tank linings can often be repaired, but undetected leaks threaten corrosion to the substrate, loss of structural integrity and even catastrophic tank failure. Silent leaks can result in contamination of ground water. In addition to loss of material, leaks pose the risk of personal injury as well as liability for property damage, lost productivity, and sometimes fines and major clean-up and repair costs.

While it may be wise to rely on redundant equipment, *i.e.*, spare tanks, to maintain production reliability, it's best to have the longest lasting, affordable solution. Some rely on a supplier's guarantee. But what is the purpose of a short guarantee for a tank expected to be in service for years? Decisions should consider the total cost of ownership.

Too many rely on information obtained from the Internet. Quality and accuracy vary widely. There is no editor responsible for content and no recourse if one is led astray. Make your supplier a team member. His expertise is a valuable asset.

Causes of premature failure

At a recent NACE Corrosion conference Mike O'Brien[2] listed the causes

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of tank coating failures. Many of the factors apply to tank liners too. He noted that all coatings fail eventually, some fail prematurely, many failures are costly and most failures are preventable. The most common causes of premature failure were:

1. Improper surface preparation,
2. A bad batch of material
3. Improper application
4. Poor specifications
5. Improper design
6. Faulty inspection
7. Equipment malfunction.

The common denominator is people. The key to avoiding failures is to develop and follow procedures that anticipate and address common human mistakes.

The most important property of any coating or lining system is adhesion to the substrate. Proper surface preparation is critical. When applied to concrete it is important to check for moisture content and for moisture vapor transmission. The surface must be free from contaminants and laitance, loosely adhering concrete and dust. Oil and grease must be removed. Experts note that abrasive blasting does not remove oil and grease or soluble salts.

Tanks and linings

Tanks are used throughout industry for storage of liquids. The familiar round tanks serve this function well. The process industry has special requirements. Rectangular tanks are common, often with special features such as sloping bottoms, or fittings.

Much of the process industry relies on plastic tanks or on plastic linings or liners in steel tanks or concrete pits (Linings differ from liners in that linings are bonded to the tank's surface, while liners are free standing within the tank.). Experience has shown they are economical compared to the alternatives and offer a long, reliable service life. As shown in Table 1, the plastic used can be matched to the service requirements from an array of choices. Plastics offer excellent resistance to acids and alkalis. Temperature and pressure can impose limitations. Resistance to impact can be a significant consideration.

Vinyl (flexible PVC) is a mainstay of the industry because it bonds well (if the surface is properly prepared and primer and adhesive specifications are followed) and offers long-term ther-

Table 1
Plastics used in tanks as liners or linings

Material	Relative cost	Resistance				Izod impact	Thermal Expansion In/in/C×10^{-5}	Maximum Tensile, psi	Fire properties	
		Acids	Alkalis	Oxidizers	Organic solvents				LOI	Self-extinguishing?
Rigid PVC: Type 1	100	+	+	+	NR	0.7	5.8	7500	37	Yes
Rigid PVC: Type 2	110	+	+	+	NR	18.0	6.3	7000	35	Yes
Vinyl	90	+	+	+	NR	No break	5.5	2000	35	Yes
CPVC	160	+	+	+	NR	1.5[A]	6.1	8000	60	Yes
PPL[B]	80[C]	+	+	NR	NR	0.9	11.7	4000	17	No
CoPPL[B,D]	”	+	+	NR	NR	No break	11.7	3500	17	No
FRP[E]	140	+	+	NR	NR	1.0	.4	18000	33	Yes
ECTFE	420	+	+	+	+	No break	9.2	4600	60	Yes
PVDF	360	+	NR	+	+	8.0	14	6000	45	Yes
Rubber	120	+	+	NR	NR	No break	Varies	3000	20	No

Notes: [A]Increases at elevated temperatures; [B]Flammable; [C]Excludes cost of steel support; [D]Difficult to weld; [E]Requires periodic topcoating.

Key: LOI - Limiting Oxygen Index, the minimum percent of oxygen in nitrogen needed to support combustion, per ASTM D2863; PVC - Polyvinyl Chloride; Vinyl - Specially Formulated Flexible Polyvinyl Chloride; CPVC - Chlorinated Polyvinyl Chloride; PPL - Polypropylene; CoPPL - Copolymer Polypropylene; FRP - Fiberglass Reinforced Plastic; PTFE - Polytetrafluoroethylene; ECTFE - Ethylene Chlorotrifluoroethylene Copolymer; PVDF - Polyvinylidene Fluoride (flex grade); +, Acceptable; NR, Not Recommended

Source: Supplier's datasheets

moplastic weld reparability. Two lined outdoor pit installations are shown in Fig. 1. Although vinyl is flexible and tough, damage can occur where parts or equipment repeatedly contact the liner surface. Examples include abrasion, cuts, extreme impact, etc. Bumpers or even acid bricks may be used to protect the liner in those situations.

More exotic fluoropolymers such as polyvinylidene fluoride (PVDF) are also available. They offer resistance to a wider range of materials including organic solvents, and can be used at higher temperatures.

Rubber linings have long been used in industry. They are installed by applying sheets of rubber compound to the tank surfaces and then vulcanizing in place, usually by the application of steam heat under pressure in an autoclave. The lining may be repaired by similar application of heat or with chemical curing agents. Additives in the compound allow adjustment of the hardness and flexibility of the cured rubber. The cumbersome curing conditions limit utility in many process situations. Most users have switched to synthetics due to the conveniences offered by thermoplastic welding. Some continue to use rubber linings, which are even more difficult to repair.

Lead is a traditional lining material especially for acids. Lead-lined wooden tanks once were common. The development of modern alternatives, the difficulty of repairing linings and toxicity issues now make lead linings a rarity.

Thermal expansion stresses the plastic. Tank design must allow for expansion for best results. Higher rates of expansion increase the severity of this aspect. Tensile strength is a measure of mechanical strength. Weaker materials can be accommodated with increased wall thickness.

Some tanks may be successfully protected with coatings, but linings or rigid plastic liners offer a much thicker barrier layer and longer service life in many applications. For an immersion application a typical coating is a minimum of 0.76 mm (30 mils or 0.030 in.) thick. A typical bonded PVC lining is 4.8 mm (3/16" or 0.188 in.) thick.

In a recent survey,[3] 50% of companies said tanks and linings have not advanced as expected. Nearly 80% have experienced tank leaks, 50% rate their leaks as a major cost burden and 10% have had a catastrophic failure.

Asked for their list of priorities, customers ask for seamless linings, easier detection of leaks, increased service life, monitoring systems, lower cost and improved shock resistance. Liner technology continues to move toward those goals.

A traditional wisdom has grown up about tank liners. They are thought to be commodities. All are alike. Hence, buyers tend to buy on price, overlooking the cost of downtime. One must be careful about lowball bids based on use of inferior materials and/or methods.

Plastic tanks

Plastic tanks are popular due to their low cost. Most are fabricated from plastic sheets. Steel frames are often used to provide strength and rigidity. The steel can be enclosed in plastic to protect from corrosion or rusting, but

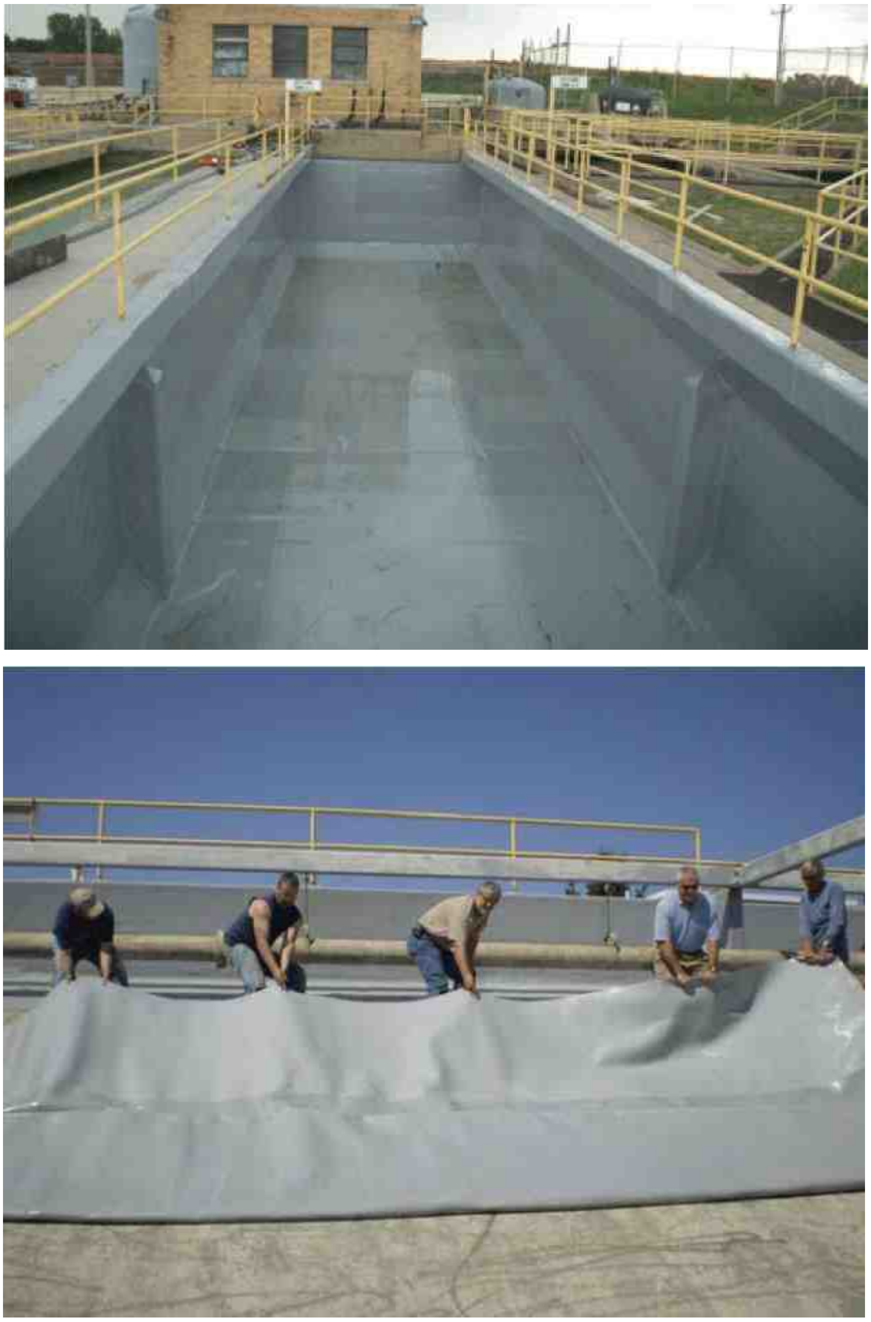

Figure 1 - *Outdoor vinyl-lined pits and their construction.*

differing rates of thermal expansion can introduce stresses and promote cracking. Similarly, special tank shapes may introduce stresses which pose design issues.

Polypropylene (PPL) is an economical material of construction, but it is flammable. Of thirty plastics tested, PPL was rated worst as a fire hazard. Once ignited, PPL burns vigorously and up to three times hotter than wood or paper. Temperatures up to 1093°C (or 2000°F) are reached, sufficient to cause steel to lose strength and buildings to collapse. Firefighting is made more complex by the presence of hazardous materials. Some plants have been a total loss. One such fire is pictured in Fig. 2.

Over a ten-year period, FM Global reported 34 fires in heated plastic tanks.[4] The average cost per incident is now $2.2MM. Immersion heaters have been implicated, but many are caused by other electrical components. Fire retarded grades of polypropylene are known, but so far they have not proved suitable in process tanks. Use of polypropylene poses a significant risk of fire.

Another of its limitations is that homopolymer PPL is rather brittle and may crack upon impact. Copolymer PPL is more resistant to cracking but is far more difficult to weld.[5]

Rigid PVC offers excellent fire properties. It is slow to ignite; flame spread is slow. When the flame source is removed, PVC ceases to burn. Tests have shown that burning polypropylene releases 14 times more heat than PVC.[6] All PVC is not created equal. High performance grades and more flexible grades are available when the application requires it.

CPVC is the next step up from PVC. It can be used at higher temperatures and higher pressures than PVC. Due to its higher chlorine content, CPVC also offers still more resistance to fire.

"Fiberglass" tanks, or more correctly tanks constructed of fiberglass reinforced composites, should be mentioned. They can be suitable when properly matched to the materials to be contained. FRP is brittle and must be maintained by periodically applying topcoats, another source of downtime. Steel tanks with linings offer a longer service life with fewer problems.

Tank linings

Lined tanks are widely used in the finishing industry - especially for corrosives. The substrate provides structural integrity. The lining protects the tank from corrosion and the tank contents from contamination. In electroplating, the lining also provides electrical insulation.

Figure 2 - *Damage from a process tank fire.*

For best results, the steel tank is blasted or the concrete etched before the lining is bonded to the substrate with a suitable adhesive. Bonding to tank walls prevents rusting and avoids stress crack failures from wrinkles in drop-in bag liners. Plastic welding then seals the seams and corners. Improved fabrication techniques reduce weld failures and increase strength. Ownership costs are lower over the life of the tank.

Field experience as confirmed by a survey[3] has noted some concerns regarding bonded PVC linings. Most often noted are:

1. Repairs require outside services
2. Disposal of used lining material
3. Leaks from pinholes and weld failure
4. Separation of the bonded liner from the substrate
5. Old linings that have started to leak or crack
6. Pitfalls of AC high voltage testing.

The industry continues to develop to provide better performance.

One innovation is newly deployed extrusion welding used to seal seams and infuse molten material into the steel corners (patent applied for). The result is a much stronger weld that is more tolerant of stresses. That reduces the probability of leaks and increases service life. In addition, if a leak occurs, solution does NOT flow behind voids or channels present with conventional corner and seam strip welding.

Extrusion welding offers additional advantages. Fully melting the welding rod results in a homogenous weld with fewer stresses. The weld is formed in a single pass, further reducing stresses introduced by the multiple passes common in traditional hand welding. The weld is faster and is less sensitive to surface oxidation.[7]

The improved, high strength extrusion weld is shown in Fig. 3. Data in Table 2 demonstrate the greater tensile strength of the extrusion weld compared to traditional hot gas welding.

Corners are a common weakness in lined tanks. Welding the three intersecting seams has been difficult. As shown in Fig. 4, the problem is resolved by welding a molded insert into the corner.

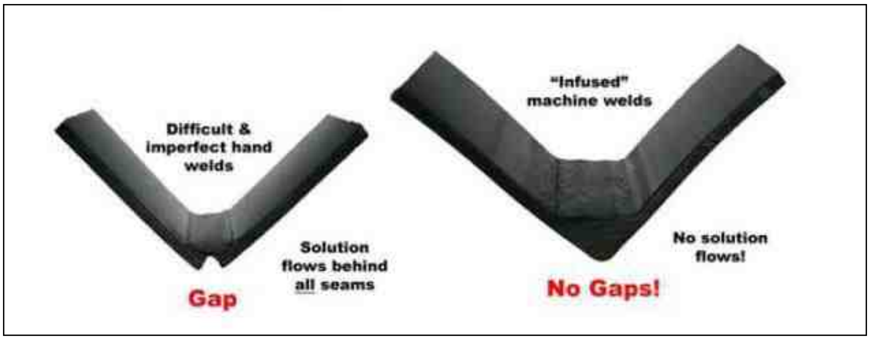

Figure 3 - *Improved, high strength extrusion weld.*

Table 2
The improved strength of extrusion welds compared to traditional hot-gas welding

Welding Process	Minimum long term tensile welding factor, f_s				
	HDPE	PPL	CPVC	PVC I/II	PVDF
Heated Tool welding	0.8	0.8	0.6	0.6	0.6
Extrusion Welding	0.6	0.6	—	—	—
Hot-gas Welding	0.4	0.4	0.4	0.4	0.4

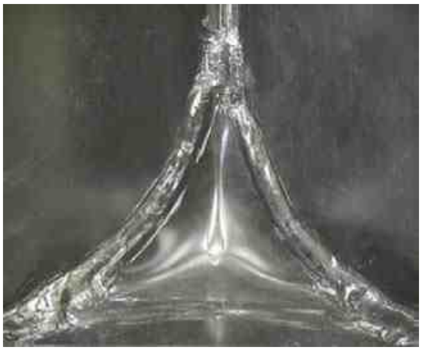

Figure 4 - *Welded insert (patent applied for) provides stronger corners.*

A typical installation using extrusion welding is shown in Fig. 5.

Another improvement is the use of radio frequency (RF) machine welding to make full panels for the walls and bottom. If the tank is very large, large sub-panels are joined by skived edges (to avoid entrapped air, similar to rubber lining joints) with overlap extrusion welds. The goal is to eliminate hand welds with seam strips in immersion service.

Bag liners

"Bag" liners are fabricated from flexible plastics with RF-welded seams. They are a low cost solution to a leaking tank that is otherwise difficult to repair. The liner relies on the tank substrate to support the load. The liner must be fitted carefully to avoid wrinkling or stretching as the tank flexes under load. Stress points can cause leaks. Leaks can be difficult to find and repair. The liner may float and move into the working area. Inspection of steel and weld integrity may not occur if just dropping-in a bag liner. Rusting behind the liner may not be inhibited. Corrosion from previous leaks may continue unabated.

Do bag liners really save money? Experience indicates they are not a substitute for bonded liners. They should be considered a temporary remedy.

Rigid drop-in liners

Rigid liners may be fabricated from heavier plastic sheets, typically from PVC, CPVC, CoPPL or PVDF. Some suppliers assemble "stick-built" liners within the tank, but this allows only weak, surface welds. In-place assembly can result in buckling (due to thermal expansion in heated tanks), stress cracking and cracked welds.

Assembly in the shop allows the use of state-of-the-art plastic welding featuring 90° thermally-formed, machine bent, rounded corners with machine pressure butt-welded side walls for maximum strength and integrity. The sidewall/bottom joint is a routed mechanical lock-in with machine extrusion welding. Molded corner inserts (patent applied for) allow for continuous extrusion welding in the problematic inner corners.

To provide double and maximum solution containment, a rigid PVC drop-in liner may include bonded vinyl on either the inside or outside of the rigid shell. A conductive bonding adhesive with a ground connection allows for leak detection, permeation monitoring or DC spark testing.

Liners must be undersized to allow for thermal expansion and yet the walls must be supported in void areas to accommodate the load of a full tank. A bumper system may be placed under the liner for absorbing shock. Properly made rigid liners provide excellent service life. They are stronger and more resistant to mechanical damage.

Leaching

Tradition has it that new tanks or liners must be leached before filling with process solution. This may not be the case with all materials and may be a cost to avoid, if one can safely do so.

Spark testing / leak detection

In an era of strict attention to the environment and especially ground water contamination, early detection of leaks is important when toxic materials are being handled. In new construction, double bottom tanks and/or secondary containment are now common. Prompt detection of leaks allows for repair before the damage becomes extensive.

Dielectric testing, usually called "spark testing," is traditionally used to detect pin holes in tank linings. Leaks are found by a point source of voltage applied across the liner. Sparking occurs when a gap in the liner allows the pas-

Figure 5 - *Typical rigid PVC liner with extrusion welding bordering air sparger pipe, including corner inserts (patent applied for).*

Figure 6 - *Hard chromium plating tank with PTFE skirting.*

sage of current to the ground (conductive substrate). A limitation is that heat from the arc can burn holes in the tank liner. In addition, the tank must be dry to avoid inaccurate readings.

For thin coatings, a battery operated wet sponge tester is grounded to the substrate and an alarm sounds if a circuit is created, *i.e.*, moisture goes through a pin hole or holiday. Although effective, this method is time consuming as it requires wetting the entire tank surface one small section at a time. For thicker plastic or rubber linings, high voltage AC spark testers are commonly used. Small hand-held models may not be calibrated for the liner material and its thickness, thus relying solely on the skill of the operator to rapidly test for leaks without doing damage. Modern DC testers can automatically adjust the test voltage to the liner and signal leaks with alarms as well as by sparking. Newer models reduce voltage as soon as the circuit is created to minimize damage.

Many believe spark testing doesn't work on lined concrete tanks. To the contrary, DC spark testing is effective. A nail driven into the concrete exterior serves as the ground contact. A second nail contact signals sufficient moisture in the concrete to permit testing.

New technology can locate leaks electronically without draining the tank.[8] This technology greatly reduces the time needed to check for leaks. Hence, frequent monitoring becomes less a hassle. Leaks can be detected sooner before damage becomes extensive.

Cathodic protection

Cathodic protection is a proven technology for protecting ductile pipelines and steel tanks and has also been used to protect lined electroplating tanks as well. By applying DC potential, the steel tank is protected from corrosion and a pinhole leak is plated again and again. This can result in a sizeable deposit of metal, sometimes called a "tree." Although plating exposed steel may be preferable to a corroded steel leak, the tree can create plating problems and eventually get in the way of the parts. Modern instrumentation can find this liner breach and allow repair on a scheduled basis.

Innovations

An example of design improvements based on experience is the use of PTFE or PVDF skirting to extend the service life in PVC or CPVC lined tanks used in hard chromium plating. The skirting protects from cracking usually observed at the air interface. A typical hard chromium plating tank with PTFE skirting appears in Fig. 6.

Another innovation is a concrete anchoring technique using an inverted V-notch cut into the concrete. Linings can be secured by infusing weld plastic into the notch essentially welding the lining to the concrete. A sample is shown in Fig. 7.

Similarly, fittings are difficult to protect in lined tanks because fittings often require that the lining be hand welded. Pumping over the side is a preferred design feature that avoids the problem of protecting fittings.

Techniques have been developed to detect leaks in double walled and/or bottom tanks. By filling the outer tank with water to a height of about 5 cm (2 in.) above the bottom of the inner tank, leaks are detected by measuring current flow in the water. The water also prevents an inner tank leak from rushing acid into an air void that wants to be filled. The water provides another level of risk mitigation thanks to the laws of fluid dynamics.

Figure 7 - *V-Notch technique to anchor lining to concrete.*

The ideal supplier

The ideal supplier works with you as a partner. His purpose is to meet your need with the best overall solution. Your last liner may have been installed many years ago. Your supplier should be up-to-date on the most recent developments, and be prepared to service your needs for the life of your tank. His experience is a major asset in helping you select the right material for your application and install it correctly. Look for advances that can improve your results and your bottom line.

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About the author

Curtis Goad, CEF, is President of GOAD COMPANY, with locations in St. Louis and Kansas City, Missouri. He grew up in the family business, attending his first AESF National Convention at age 12, and working summers through his school years. From GOAD's early lead-burning days, the company progressed through a multitude of material advancements. Curtis has a patent on detecting pre-leaks in full tanks to prevent downtime, and a patent pending on a tank lining / welding technology breakthrough. He degreed at both Miami University (Ohio) and the University of Missouri, Columbia, and is a longtime member of the National Association for Surface Finishing (NASF), NACE® International, The Corrosion Society - SSPC, The Society for Protective Coatings and the Missouri Bar.

Answers to I.Q. Quiz #466 from page 7.

1. Prior to flocculation, the ingredients to be treated are in suspension, whereas prior to precipitation, they are dissolved in solution.
2. Particles finer than 0.1 µm in water remain continuously in motion due to electrostatic charge (often negative) which causes them to repel each other. Flocculation neutralizes this charge and finer particles start to agglomerate.
3. Coagulants function much like flocculants. However, they typically have a significantly lower molecular weight and are usually inorganic metal salts, which generally form insoluble hydroxides when added to pH adjusted wastewater.
4. False. They generally have a shelf life of only 24 to 48 hours, and therefore should only be blended at the time of treatment. Keeping large inventories is not prudent, owing to biologic and chemical degradation tendencies.
5. False. Flocculant particles are actually quite fragile and can be destroyed by excessive agitation. Slowly rotating paddle-type mixers are recommended.