t has been almost 30 years since the U.S. Environmental Protection Agency (EPA), through the Federal Water Pollution Control Act of 1965 and the Amendments of 1972, helped fund a massive program for the construction of municipal wastewater treatment plants throughout the U.S. As time has passed, it has become painfully evident to many design engineers and utilities that the corrosion conditions to which these structures are subjected are some of the most aggressive conditions in the industry. Although much has been written about microbiologically influenced corrosion (MIC) in municipal wastewater collection and treatment, the full extent of its potential for damage has only recently been understood (Fig. 1). Because of their natural elasticity, resistance to microbial attack, impermeability, and unlimited film build, some solventless elastomeric polyurethane coatings have accumulated a significant track record in the protection of concrete and carbon steel surfaces exposed to MIC in wastewater collection and treatment (Fig. 2). Regardless of their apparently ideal characteristics, however, their unusual application requirements pose certain challenges to the unwary user or specifier, especially in their application to an already difficult substrate, concrete.

The fundamentals of writing specifications, preparing work procedures, painting, and inspecting concrete have been detailed elsewhere. This article will outline a set of practical guidelines for the use of solventless elastomeric polyurethanes on concrete structures in municipal wastewater collection and treatment. The article will show the reader how to avoid easily prevented problems and how to deal with problems that cannot be prevented.

**Specifier Considerations**

**Specs vs. Recommendations**

Because of the extensive detail in general construction specifications, the coating section is typically brief. Usually, it is limited to describing...
systems and procedures that directly affect the price of the work and standards that define the quality of the results.

The inherent complexity of solventless elastomeric polyurethanes, however, requires much more information than is usually provided by the specifications. The contract document may simply make multiple references to “follow the manufacturer’s recommendations.” Unfortunately, the interpretation of these recommendations on issues that are not typically covered by the contract specifications (i.e., recoat times, mixing instructions, and technique) can vary widely, especially after a problem develops.

Therefore, the contract specifications should require the bidder’s proposal to include project-specific recommendations from the manufacturer. This requirement obliges the contractor to call the coatings manufacturer and discuss details and eliminates many assumptions.

**Applicator Qualifications**

The specifier can avoid many application problems by restricting the bidding to good professional applicators who are factory trained and who have experience in applying the same coating material to concrete in similar structures. If the specification is not clear on this matter, many general contractors will simply assume that this “newfangled” polyurethane is just another paint that the house painter can handle. They will bid a ballpark figure for this part of the work, which is usually grossly underestimated and destined for major disputes.

Therefore, it is critical that the contract specifications alert the general contractor that these coating materials must be applied by experienced sub-contractors with specialized application equipment and factory-trained personnel. The specifications should also note that if, in the opinion of the engineer, the subcontractor has insufficient experience in the application of the specified coating materials, the general contractor may have to assume the cost of coating inspection on the entire job. This item in the specs or bid package usually gets their attention, because it could place them at a competitive disadvantage to other contractors that sub-contract experienced, factory-qualified personnel who are properly equipped to perform the work.

Unfortunately, experienced applicators may not always be available to bid on jobs requiring elastomeric polyurethane. In this case, the prospective applicator needs to estimate the cost of the specialized plural-component spray equipment and factory technicians for on-the-job training, and the owner needs to procure third-party inspection.

**Case Histories and References**

The specifier should request that the bidder obtain references and case histories from the coating manufacturer. This request eliminates the huge risk of allowing the contractor to use unproven coating materials. In particular, solventless elastomeric polyurethane chemistry allows for wide latitude in physical, performance, and application characteristics among formulations said to be generically equal. It is risky to assume that different brands are truly equal.

**Equipment Requirements**

It is a mistake to assume that as long as a plural-component spray machine is the same volume ratio as that of the material to be sprayed, all is well. Solventless elastomeric polyurethanes can have radically different flow and cure characteristics, even if the volume ratios are the same. Successful plural component application depends greatly on its relative ease of use. In the world of
plural-component, spray-applied, solventless elastomeric polyurethanes, successful application usually means the right equipment design, from the supply systems to the spray gun.

The specifier should insist that the applicator use equipment configured correctly for the coating material. If applicators will be trained on the job, the specifier should require the coating manufacturer to certify that the spray equipment is configured properly.

Surface Considerations

Cavities on New Concrete

The surface preparation of new concrete structures seems, at first glance, relatively easy. No decontamination is needed, and there is no loose aggregate or flash rusting as in the case of carbon steel. Poured floors and ceilings may not present continued
problems, but vertical concrete structures are another story. Concrete for walls is typically poured into forms and then is consolidated by vibration to eliminate air pockets and increase density. Regardless of the contractor’s best efforts to eliminate them, many air pockets remain when the forms are removed. In the case of air-entrained concrete, sometimes specified for its light weight and load-bearing capabilities, it is a foregone conclusion that air pockets, referred to in the industry vernacular as “bugholes,” will be extensive (Fig. 3).

Abrasive blasting of vertical structures further aggravates the situation by breaking the thin crusts that cover the air pockets, opening even more bugholes.

A solventless elastomeric polyurethane with unlimited film build characteristics will cover many of the smaller bugholes, but larger bug-
holes are difficult, if not impossible, to coat unless they are resurfaced or treated. Usually, before coating, these bugholes are filled with resurfacers such as solventless epoxy putties or high early strength cementitious compounds. Thinner film coatings may need 100 percent resurfacing of bugholes to produce a pinhole-free membrane, which is, after all, the objective.

**Fiberglass To Fill Cavities**

If the selected coating material does have unlimited film build, an innovative technique can eliminate most resurfacing on flat, vertical concrete surfaces that exhibit extensive cavities or bugholes after abrasive blasting. This technique consists of an initial spray application of coating material at 20-30 mils (0.5 to 0.8 mm), applied directly to the abrasive-blasted concrete. While the applied coating is still in a semi-fluid condition, a fiberglass mesh or screen is laid flat against the coated surface. It is embedded into the base coat by pressing it with a non-stick roller or trowel, ensuring that the base coat is of a consistency that will support the screen. If folds or wrinkles are present in the installed screen, they are cut with a razor so that the screen lays flat against the surface. After screen installation, the remaining topcoat material is spray applied directly over the screen to bridge all cavities and produce the specified coating dry film thickness (dft), usually 80 mils (2 mm).

This procedure eliminates the potential for failure of the resurfacing materials. It also makes the treatment of cavities a hard bid item, thus reducing the price and substantially accelerating the installation time and return to service. Concrete surfaces with excessive cavities, where a fiberglass screen is impossible or impractical to use, still need to be resurfaced before coating.
Treating Deteriorated Concrete

Rehabilitation of concrete surfaces that have been in wastewater service usually involves dealing with gross contamination by oils and greases, exposed aggregate, spilled concrete, corroded rebar, and leaks. On rehabilitation jobs, it is often most helpful to assume the worst.

The only positive factor in a rehab job will probably be the lack of bugholes in the concrete. Where did the bugholes go? By the time a wastewater structure is slated for rehabilitation, the deterioration of the concrete is usually so severe that, after decontamination and abrasive blasting, only exposed aggregate remains on the surface. If unprotected, the fine cement matrix of the concrete, which also makes up the crusts around an air pocket, is the first component of the concrete to succumb to bacterial attack.

Specifying a substantially higher thickness than that required for new concrete is all that is needed if solventless elastomeric polyurethanes with unlimited film build in 1 application are used and if a smooth surface is not required. These products are usually specified at thicknesses of 125 mils (3.2 mm) or higher for rehab work, making it relatively simple to bury the extremely rough surface with a monolithic membrane. This result would be impossible with thinner films or with high build coatings that cannot be applied at their ultimate thickness in 1 application.

As always, there are exceptions. Some concrete structures have been so badly attacked that their structural integrity is in question. Deterioration by MIC can be so extensive that no coating will restore the concrete, regardless of the film thickness applied. Before start-up of coating operations, the specifier should request that the applicator first apply 1 or more test patches to determine the need for resurfacing, if any. If test patches prove that the surface is too rough for the applicator to achieve a monolithic, pinhole-free membrane at the dft specified, usually 125 mils (3 mm) for exposed aggregate, the contractor has 2 options. One option is to increase the coating thickness. Another is to resurface the affected area with a non-shrink, quick-setting cementitious grout before coating and reduce coating film thickness to approximately 80 mils (2 mm). The economics of each alternative should be assessed before the contractor proceeds with coating work.

It is important for the applicator to remember that, when coating deteriorated concrete surfaces, the bottom surfaces of exposed aggregate also

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need protection. To make sure that all bare surfaces on exposed aggregate or other high-profile protrusions are properly coated, use of a “four-way pass” spray technique is highly recommended.

**Water Problems**
Concrete cracks, leaks, moves, shrinks, absorbs water, and releases water vapor. These characteristics make concrete difficult to coat.

**Leak Repairs**
Active leaks, as found in most below-grade structures such as sewer manholes and pump stations, they must be repaired before coating. In the author’s experience, no solventless elastomeric polyurethane coating can be applied directly over an active leak without blistering. Many products are available for repairing leaks, but the most reliable repair systems are those that plug the leak from its source, the exterior (or positive) side of the wall to be coated. This repair usually consists of drilling through the wall at the leak and injecting a quick-setting epoxy or urethane foam compound. This technique stops the infiltration of water at its source. Products that repair leaks from the negative side of the wall (the side to be coated) may not hold up to continuing hydrostatic pressure.

**Damp Surfaces**
Repairing active leaks does not necessarily result in a dry concrete surface. In many cases, the amount of surface moisture does not depend on the presence of leaks or infiltrations. Although all concrete structures contain some water, the surface moisture depends on the relative porosity of the concrete and the amount of water available in the immediate environment. Capillaries within the concrete turn the structure into a sponge or wick, drawing water from the ground or the air.
The probability for excessive surface moisture is substantially greater if a concrete structure is at-grade or below-grade. Structures or sections of structures located above-grade, such as digester ceilings, may have insignificant amounts of moisture.

The amount of moisture allowed on the surface before application of solventless elastomeric polyurethanes depends mostly on the moisture tolerance of the product. This particular characteristic can vary widely among solventless elastomeric polyurethane formulations, and some have no resistance to surface moisture at all.

Some manufacturers have developed moisture-tolerant epoxy primers specifically for this application, using them to isolate surface moisture from the urethane coating. A primer should be used only when absolutely necessary, as most solventless elastomeric polyurethanes develop excellent adhesion to properly prepared concrete that is relatively free of surface moisture, without the need of a “moisture-tolerant” primer.

**Hydrostatic Conditions**

A hydrostatic condition refers to an actual pressure force, as opposed to surface moisture produced by the capillarity of the concrete or water from leaks. This force is created by the weight of a column of water exerted against a concrete surface located adjacent to the water column. The magnitude of hydrostatic pressure at any given point on the interior surface (negative-side) of a below-grade concrete structure is mostly dependent on the height of the water column above that point. However, the actual force exerted is dissipated to some degree by the relative percolation rates of surrounding soil and the relative permeability of the concrete itself. The magnitude of hydrostatic pressure at any point on the interior surface (negative side) of the concrete is dependent on the height of the water column above that point and the permeability of the surrounding soil and of the concrete.

On below-grade surfaces, hydrostatic pressure is created by the weight of the water contained within adjacent saturated soil. On below-grade vertical surfaces, hydrostatic pressure force vectors are horizontal. On below-grade floor slabs, the force vectors are vertical.

When an impermeable coating is applied to the interior of concrete surfaces subjected to excessive hydrostatic pressure, water pressure accumulates rapidly against the backside of the applied coating.
system and causes the coating to fully or partially disbond from the surface, producing water-filled blisters.

But how much pressure is actually exerted against the lining by hydrostatic conditions? A foot of "head" pressure, or the weight of the water column discussed earlier, is equivalent to approximately 0.43 psi (3 kPa), without considering the relative permeability of the saturated soil and the concrete itself. This pressure is exerted against the coating. If such forces exceed the coating's adhesion to the concrete, it will disbond.

Therefore, the real question may lie in the kind of adhesion that solventless elastomeric polyurethanes develop on concrete. Most of these products are designed to achieve adhesion to concrete greater than that of the concrete to itself, or its tensile or cohesive strength. Many engineers agree that the cohesive strength of concrete is about 10 percent of its compressive strength. So, for instance, if the concrete has a design compressive strength of 5,000 psi (34 MPa), its cohesive strength will be approximately 500 psi (3.4 MPa). For hydrostatic pressures to be greater than the adhesion of the coating to concrete with compressive strength of 5,000 psi, the concrete structure would have to be located more than 1,162 ft (349 m) below grade, once the relative permeability of the soil and the concrete slab is factored in. Fortunately, the author has not encountered any wastewater treatment installations at that depth.

How much hydrostatic pressure is allowed? Once installed, the applied coating must resist all hydrostatic pressure to which it may be subjected, but during application of the coating, the safest amount of pressure is, of course, none at all. Solventless elastomeric polyurethanes are well-known for their speed to cure and, in most cases, they will quickly develop sufficient adhesion to the concrete with the ability to resist such pressures within a matter of hours after application. If they are not subjected to excessive hydrostatic pressures during this initial period, they have an excellent chance of remaining well-adhered and of resisting most hydrostatic forces indefinitely.

Outgassing

Outgassing is a frustrating problem in the installation of a pinhole-free solventless elastomeric polyurethane membrane.

The outgassing effect is explained as follows: concrete releases air and water vapor that expands when tem-
temperatures rise, and, conversely, concrete absorbs air and water vapor that constricts when temperatures drop. This is because air and water vapor, like all elements in nature, seek thermal equilibrium with their surroundings. When outgassing occurs, it produces pinholes in the coating. The degree of outgassing is sometimes increased by some elastomeric polyurethanes that generate heat during their initial cure, adding even more heat to the surface of the concrete.

Although some concrete sealers are said to stop outgassing, the author is not aware of any that make a substantial difference in the reduction of outgassing that produces pinholes. It is important to remember that air and water vapor, not water in its liquid state, must be sealed. Water in the liquid state has a much higher surface tension than water vapor and can be more easily deterred in its movement through the capillaries of the concrete.

How can the applicator deal with this problem? First, the applicator needs to be aware that outgassing is happening. Close observation of the initial application of the coating (20 to 30 mils; 0.5 to 0.8 mm) to the concrete surface is essential.

If pinholing is excessive, the coating will have to be sprayed in increments. The applicator will have to allow the previous increment to dry, gain tensile strength, and cool down from its exothermic reaction before applying additional increments. The thinner the increment, the lower the exothermic effect. In addition, the initial increment acts as insulation, radically reducing the outgassing effect caused by the exothermic reaction of subsequent coats.

The applicator should try to program coating application to coincide with a cooling trend on the concrete’s surface, usually late in the afternoon. Before job start-up, surface temperatures should be monitored to determine the cooling-heating trends of the areas to be coated. If a cooling trend is not detected, then the only thing one can do is be patient and put the coating on in as many increments as possible.

The applicator can start with an initial increment of 20-30 mils (0.5-0.8 mm), then divide the rest of the film thickness required into additional increments of similar thickness, with the total number depending on the degree of outgassing. Otherwise, if the applicator sprays an initial increment of 20-30 (0.5-0.8 mm) mils and observes few or no pinholes, the entire coating thickness can be applied in 1 or 2 increments at the most, assuming a solventless elastomer.

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tomer polyurethane with unlimited film build in one coat.

For best results in the case of solventless systems, increments are usually applied within an hour or so from each other, and the final film thickness must be applied to a particular area by the end of the day. Specific time intervals between increments will vary, however, depending mostly on ambient and surface temperatures as well as other conditions that can affect the cure rate and, consequently, the re-coat window of a particular formulation.

Spark Testing

For final proof of monolithic integrity in a lining applied to concrete, there is no better test than high voltage holiday detection. It is never easy to produce a pinhole-free membrane on concrete, and spark testing is so conclusive that many contractors and more than a few coatings manufacturers shudder at the mere thought. A good ASTM standard10 is available on spark testing. Below are a few tips on when to conduct spark testing and what to avoid.

The amount of pinholing experienced during application of liquid-applied coatings may vary widely on the same job, making it extremely important to monitor and re-assess outgassing and pinholing on an hour-by-hour or day-by-day basis.

Therefore, assuming that the applied coating cures sufficiently to allow spark testing 8 to 12 hours after application, all coating work should be spark tested first thing the next morning before the start of further coating work. This prompt inspection allows the application crew to see for themselves, at the earliest possible time, how successful they were in achieving a pinhole-free membrane on the section of work already completed. If necessary, the applicator can make changes in style or technique that can rectify the situation in a timely manner.

It can be a big mistake, especially on larger projects, to allow the applicators to work until finished, demobilize, then call for the inspector. This approach to holiday detection is asking the applicators to do the impossible: assess the degree of outgassing and pinholing with the unaided eye, when, in fact, some pinholes can be microscopic in size.

Insofar as the actual spark testing procedure is concerned, the ASTM standard gives detailed direction. The only caveat is that the conductivity of concrete, like everything else about it, may vary dramatically and the voltage settings needed to detect a holiday must be set repeat-
edly for the particular section of coated concrete being tested. Factors that tend to have an effect on the conductivity of concrete include the amount of water in the concrete and its salinity, the amount of embedded steel or its proximity to the electrode, and the effectiveness of the electrical ground.

Usually, coating manufacturers that encourage high voltage spark testing recommend an initial voltage setting to produce a spark that will bridge a gap of air equal to, or just greater than, the dry film thickness of the coating being tested. To this fixed voltage requirement must be added the relative voltage required to get a spark from the bare concrete itself, usually on a deliberately induced holiday. The sum of fixed and relative voltages can be considerable. It is not unusual to test solventless elastomeric polyure-
thanes, usually applied at 80 to 125 mils (2 to 3 mm) to concrete, at 20,000 volts. Do not try this with thin-film coatings.

Holiday detection is the most important test for a coating or lining system that will be subjected to immersion, microbiological attack, permeation by corrosive gases, and a multitude of other chemical and physical stresses.

Conclusions
Concrete structures in wastewater collection and treatment require long-term protection from extremely aggressive service conditions. Solventless elastomeric polyurethanes appear to offer one solution. A practical understanding of the behavior of concrete and its interaction with solventless elastomeric polyurethanes is essential to proper use of these materials.

Notes