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**Innovations Deserving  
Exploratory Analysis Programs**

***Highway Program***

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## **Improved Filtration of Wash Water Generated during Bridge Maintenance Painting**

Final Report for Highway-IDEA Project 72

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# Improved Filtration of Wash Water Generated during Bridge Maintenance Painting

## SUMMARY

Many state highway agencies now perform steel bridge maintenance painting by overcoating the existing paint. Typically, overcoating entails pressure washing to remove soils, bird droppings, and oxidized or poorly bonded paint, followed by application of a primer and topcoat. This method is used to minimize the possibility of release of hazardous materials into the environment and provides a lower initial cost compared to maintenance painting operations that incorporate complete removal of existing paint by abrasive blasting (with containment). The resulting wastewater often contains lead paint chips that can be partially removed by mechanically filtering the water through porous containment screens. Such filtering is ineffective in removing micron-sized particles that result from chalked or brittle paint removed by pressure washing. The total lead content of the wastewater ranges anywhere from 2 to over 1,000 parts per million (ppm) after mechanical filtering, far in excess of the 15 parts per billion (ppb) allowed in drinking water.

Although the life cycle costs of overcoating are demonstrably more attractive than the traditional alternative of complete paint removal, the high lead content of the resulting wastewater has led a number of states to abandon overcoating altogether. In other states, highway agencies are facing increasingly more restrictive regulations regarding the disposal of lead-contaminated wastewater generated by pressure washing operations. Many state environmental regulatory agencies require wastewater generated on such projects to be treated to lower lead levels prior to release, or mandate off-site disposal into sanitary sewers or at treatment facilities. More restrictive regulations are anticipated in those states which do not presently have such requirements. This project sought to develop a portable filtration system for removing both particulate and soluble lead from wastewater generated by pressure washing lead-based paint from highway bridges prior to maintenance painting operations. The ultimate goal of the project was to demonstrate a filtration system which would work on site to render bridge wastewater clean enough to discharge to surface waters or onto the ground, and to do this in a cost-effective manner.

Numerous compounds exist, both naturally-occurring and manmade, which will chemically bind free lead into an insoluble lead mineral. There are also compounds known to adsorb lead into their structures in such a manner that the lead will not readily leach out. The first phase of the project consisted of evaluating a number of these compounds in a bench-scale test to determine their efficacy in binding lead from a synthetic bridge-washing wastewater. All three of the candidate compounds, two zeolites (aluminum silicates) and a form of calcium phosphate, were found to be effective in removing lead from the simulated wastewater. In the second phase of the project, a prototype filtration system capable of processing 400 gallons of wastewater per hour was constructed for testing on bridge overcoating projects conducted by the Kentucky Transportation Cabinet. Wastewater from the bridges was captured by tarps slung beneath the bridges and pumped to a holding tank on the trailer-mounted filtration system. The wastewater was passed through a trickling sand filter to remove larger particles, and then supplied under pressure to filter columns containing the lead-binding filter media.

The prototype filtration system was employed on bridge washing projects at two locations in Kentucky in the summer of 2002. In both instances, the filtration system proved effective in removing lead from the washwater. Total lead concentrations on the order of 10 ppm were reduced to no more than 20 ppb, and in many instances as low as 3 ppb. This performance is at least competitive with any other known portable lead filtration system, including those which use centrifuging and chemical precipitation.

The project partners are working to disseminate the results of the project to state highway agencies and the bridge maintenance painting industry through a variety of forums. In addition, the project partners are presently engaged in the design of a new portable filtration system which will incorporate improvements based upon their experiences with the system tested in this project. The new system will be tested on numerous bridge overcoating projects in Kentucky during the 2003 painting season. The partners will work to optimize the system with respect to both removal efficiency and operating costs, and hope to commercialize the system in the near future. The Kentucky Transportation Cabinet has expressed considerable interest in the capabilities of the system, and there is reason to believe that the agency will eventually specify routine use of the filtration system on bridge maintenance painting projects within the state as part of the agency's commitment to employ "best practices" to safeguard the public and the environment.

## INTRODUCTION AND RESEARCH APPROACH

### PROJECT BACKGROUND

Maintenance painting is done on hundreds of steel highway bridges in the United States each year using overcoating. Overcoating typically entails pressure washing to remove soils, bird droppings, and oxidized or weakly bonded paint. Pressures ranging from 3,000 to 10,000 pounds per square inch (psi) are employed, depending upon the nature of the surface to be prepared. The cleaned surface is then mechanically prepared to remove corrosion as necessary and subsequently painted. Many state highway agencies have switched to overcoating in lieu of complete removal of the existing paint (by abrasive blasting) for a number of reasons. Overcoating offers initial unit costs that range from one-third to one-half of those required for complete stripping and re-painting. In addition, the use of overcoating minimizes the possibility of release of hazardous materials into the environment.

As is the case with abrasive blasting, pressure washing of the lead-containing paint common on many highway bridges does produce a waste stream that may be deemed hazardous per U.S. Environmental Protection Agency regulations. The spent wastewater contains paint chips that can be partially removed by mechanically filtering the water through porous containment screens rigged beneath the bridge structure. It is possible to use geotextile filter screens with apparent opening sizes as small as 200 microns; openings smaller than this will result in ponding of the wastewater on top of the screen, due to lack of adequate head pressure. The very small paint particles that remain in the wastewater result in a total lead concentration that ranges anywhere from 25 parts per million (ppm) to over 1,000 ppm; concentration is largely a function of the lead content in the existing paint, the amount of existing paint on a structure (i.e., the paint thickness), its condition, the pressure at which the surface was washed, and how much time the operator spends washing a particular area. Although the total lead concentration may not be sufficient to be considered a hazardous waste, it is in almost all cases far in excess of the 15 parts per billion (ppb) allowed in drinking water. Figure 1 shows a highway bridge being pressure washed for overcoating, with impermeable tarps rigged for full containment of the wastewater.

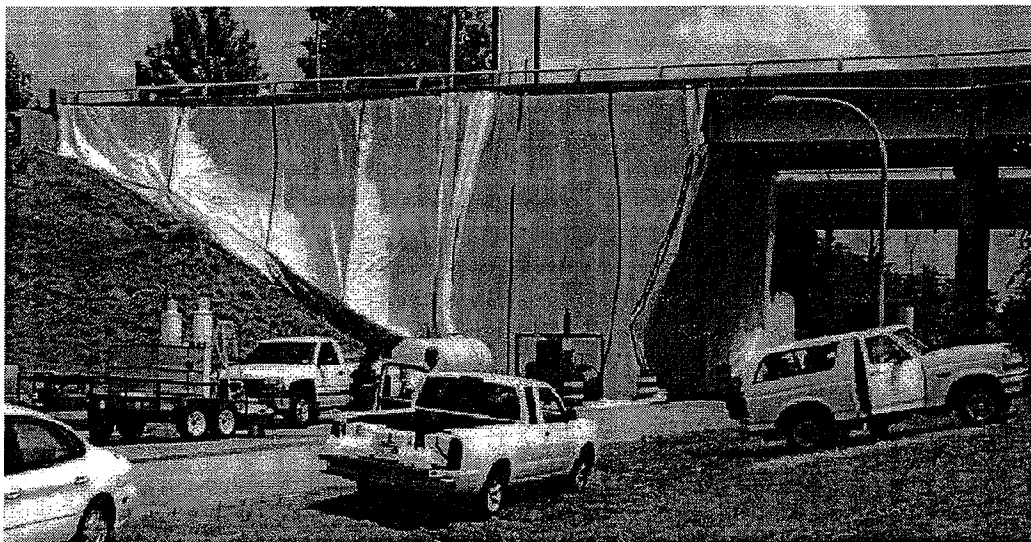


FIGURE 1 Highway Bridge Rigged for Full Containment of Wastewater from Pressure Washing

Many state environmental regulatory agencies currently require wastewater generated on overcoating projects to be treated to reduce lead levels and may also require off-site disposal into sanitary sewers or at treatment facilities. The cost of complying with these requirements has led several states, including Tennessee, to abandon overcoating as an allowable approach to bridge maintenance painting. More restrictive regulations are anticipated in those states which do not currently have such requirements.



If it were possible to remove lead from the bridge washing wastewater in a cost-effective manner using a portable filtration system, such that the filtered water could then be discharged to surface waters or onto the ground, the future of overcoating versus complete removal would be considerably brighter. Kentucky Transportation Cabinet engineers estimate the potential savings at \$5,000 to \$1,000,000 per bridge to those agencies that currently overcoat but have to ship wastewater for treatment, and as much as \$5,000,000 per bridge for those agencies that would then elect to use overcoating instead of the more costly approach of completely removing paint. The exact figure for cost avoided per bridge is dependent upon project-specific factors -- bridge size, location, regulatory requirements, proximity to sewer systems which will accept lead-bearing wastewater, etc.

Numerous compounds exist, both naturally-occurring and manmade, which will chemically bind free lead into an insoluble lead mineral. There are also compounds known to sorb lead into their structures in such a manner that the lead will not readily leach out. It was believed that some of these compounds could be made to work in a filtration system to provide a mix of mechanical and chemical filtering, and thereby address the problem..

## **RESEARCH OBJECTIVE**

The objective of the research performed in this project was to develop a portable filtration system capable of processing bridge washing wastewater containing particles of lead-bearing paint. The system was to have the capacity to treat/handle the entire wastewater flow of a typical bridge overcoating project, and to be capable of reducing the total lead content of the wastewater to the extent that it could be safely discharged to receiving waters or onto the ground. Ideally, the system would be able to reduce the total lead content of the wastewater to a concentration equal to or less than the Federal drinking water standard.

## **SCOPE OF STUDY**

This study consisted of two phases. Phase I consisted of Tasks 1 through 5, and Phase II consisted of Tasks 6 through 9. These Tasks are described below.

- Task 1. Hold discussions with Kentucky Department of Highways and Kentucky Transportation Research Center personnel to establish operational parameters for the prototype filtration system.
- Task 2. Collect and review relevant literature, research findings, performance data, current practices, and other information relative to bridge overcoating, high pressure washing of lead-bearing paint, and filtration of dissolved lead from water.
- Task 3. Identify known lead-binding or -adsorbing compounds for potential use as filter media.
- Task 4. Develop methodology for laboratory evaluation of candidate compounds to determine efficacy in removing dissolved lead from a synthetic bridge washing wastewater.
- Task 5. Conduct laboratory evaluations of candidate compounds.
- Task 6. Design and construct a prototype mobile filtration system to evaluate the performance of the most promising filter media on actual bridge overcoating projects in the state of Kentucky.
- Task 7. Operate prototype filtration system to process wastewater from bridge overcoating projects in Kentucky. Collect and analyze samples of influent and effluent to/from system to establish system performance.
- Task 8. Evaluate operational experiences and analytical results to establish degree of compliance with objectives.
- Task 9. Submit final report documenting the entire research effort.

## LABORATORY TEST PROGRAM AND TEST RESULTS

### SELECTION OF CANDIDATE FILTER MEDIA

Numerous compounds exist, both naturally-occurring and manmade, which will chemically bind free lead into an insoluble lead mineral, or sorb lead such that the resulting material will pass the EPA Toxicity Characteristic Leaching Procedure test for landfill disposal. A search of the available literature revealed a large body of experimental work had been done to determine the ability of various minerals to bind various heavy metals including lead. After seeing the large number of substances that might work as filter media in this application, a set of criteria were developed to reduce the field of potential candidates. At this point the evaluation of candidate compounds was restricted to those that possessing the following four attributes:

- (1) *Insoluble in water.* In order to be usable for water filtration in an industrial application, the filter media would need to be completely insoluble in water. Although many substances have been demonstrated to bind or sorb lead, many are themselves water soluble and therefore practically impossible to contain in a filtration system.
- (2) *Effective in binding or adsorbing lead beginning with concentrations in the 5 to 100 ppm range.* Based upon data developed from analysis of bridge overcoating projects in Kentucky, most bridge washing wastewater has a total lead concentration in the range of 5 to 100 ppm following simple mechanical filtering through containment screens. In order to be a viable candidate for use in filtering such wastewater, a compound would need to be able to tolerate exposure to lead concentrations in this range without quickly becoming saturated.
- (3) *Commercial availability.* Since the ultimate goal of this project was to lead to commercialization of a portable filtration system, it would be impractical to select and test filter media unobtainable in industrial quantities.
- (4) *Relatively low cost.* With reference to (3) above, many of the lead-binding or -adsorbing compounds found in the literature (especially minerals in the apatite family) are not available except in small quantities from scientific supply houses, and at considerable cost. In order for a prospective filter media to be considered for field testing, it would need to be available in quantity at a price that would be at least competitive with the cost of trucking bridge washing wastewater to a treatment facility for lead removal.

In applying these four criteria to the search, two groups of compounds emerged which it was believed merited further evaluation for potential use as filter media for lead removal:

- (1) **Zeolites** are framework aluminum silicates comprised of interlocking tetrahedrons of  $\text{AlO}_4$  and  $\text{SiO}_4$ . They occur naturally in the cavities of volcanic rocks as the result of very low grade metamorphic activity, but can also be manmade. There are about 45 naturally occurring minerals that can be termed zeolites, and there hundreds of manmade variations. Zeolites have found many industrial applications due to the large vacant spaces within their structures and the negative charge carried by the structure. Zeolites are thus able to attract and hold large cations and some relatively large molecules and cation groups such as water, ammonia, and nitrate ions. Significant to use in water filtration is the fact that zeolites can absorb and then lose water without damage to their structures.

Industrial applications for zeolite include ion exchange, odor removal, and filtering. Many consumers are familiar in passing with the name "zeolite" due to their most common application, water softening. Zeolites are prepared for this application by heating them to drive off any resident water molecules, and then charging them with sodium ions. When hard water flows through zeolite media prepared in this manner, the damaging calcium ions are exchanged for the far less harmful sodium ions.

A number of firms in the United States offer zeolites for general filtration use. The cost of such materials purchased in quantities of 1,000 pounds ranges from less than \$1.00/ pound for sieved green zeolites from mines in Arkansas to more than \$4.00/pound for those which have been tailored through thermal processing or other further treatment to optimize them for use in removing heavy metals from drinking water, including lead.

- (2) **Phosphate compounds** have been the subject of extensive investigation for use as lead-binding agents. Studies of soil contaminated by the introduction of smelter dross into the environment around lead smelters in south-central Missouri found that, given time, galena ore and smelter dross weathered to form a series of insoluble lead phosphates (1). Other work demonstrated that the introduction of phosphate rock into aqueous solutions and soil contaminated with lead would result in the reduction of water-soluble lead by anywhere from 38.8 to 100% (2). These and numerous other studies established that the leachability and consequent bioavailability of free lead from the resulting pyromorphite minerals was very limited, suggesting that the phosphate rock could be a very effective means for *in situ* immobilization of free lead in soil, and potentially for filtering lead from water.

After discussing the objectives of the research project with a number of suppliers, the decision was made to proceed with laboratory testing of three commercial filter media to determine their efficacy in binding or adsorbing dissolved lead from highway bridge washing wastewater. The three candidate media were selected for testing due to a demonstrated history of effectiveness in binding heavy metals, commercial availability, and the degree of cooperation provided by the supplier in determining design parameters for this application. The filter media consisted of two aluminum silicates (zeolites) and a calcium phosphate compound, as follows:

- (1) *Aqua-Bind EXP-300Z* is a zeolite supplied by Apryon Technologies Inc. of Norcross, Georgia. This zeolite was an experimental product optimized for lead removal in filter column applications through thermal processing, and supplied in a 14 x 40 mesh grade. The media sells for \$145/cubic foot (ft<sup>3</sup>) in quantities of 5 to 10 ft<sup>3</sup>.
- (2) *Fablite* is a zeolite supplied by Fabco Industries of Bohemia, New York. Consisting of a coarse brown zeolite of varying mesh sizes, the media is supplied by Fabco primarily for use in its Pure Flow FS-55 portable wastewater filtration system. Fabco markets the FS-55 system to military aircraft maintenance and industrial shops for removing heavy metals and traces of hydrocarbons from wastewaters in batch operation. The media is supplied in 20-pound bags priced at \$35 each.
- (3) *LEADX* is a form of calcium phosphate marketed as a heavy metals scavenger by Proactive Applied Solutions Corporation of Reagan, Texas. *LEADX* is supplied in fine granular form (ASTM mesh size 60 to 100) and has a specific gravity of 3.0. The media is supplied in bulk at \$480/ton (2,000 pounds).

## DETERMINATION OF TEST PARAMETERS

Test conditions were established by analysis of data supplied by the Kentucky Transportation Center (KTC) from ten bridge-washing projects completed in Kentucky during the 2001 season, and from empirical observations by KTC personnel. Samples of wastewater taken from projects during the 2001 season contained 3.3 to 15 ppm total lead and 0.1 to 6.7 ppm dissolved lead, with pH varying from 6.7 to 8.5; historical data (state highway department paint specifications) and other analytical results confirmed that red lead oxide (Pb<sub>3</sub>O<sub>4</sub>) was the source of much of the dissolved lead. It was believed that subjecting the candidate media to an effluent with 5 ppm dissolved lead at a pH between 6.0 and 7.0 would be a realistic representation of actual field conditions.

## EXPERIMENTAL APPARATUS AND TEST PROTOCOL

Initially, attempts were made to prepare a synthetic bridge washing wastewater for use in the bench-scale tests by mixing Pb<sub>3</sub>O<sub>4</sub> (1 to 2 micron mesh) with the appropriate amount of deionized water to produce a dissolved lead concentration of 5 ppm; the solution was rendered slightly acidic with the addition of hydrochloric acid to force as much of the lead oxide into solution as possible. Analysis of the resulting solution revealed that the solubility of the red lead oxide varied widely with pH, to the extent that it was impossible to prepare a solution of a given dissolved lead concentration by adding Pb<sub>3</sub>O<sub>4</sub> to a quantity of water of a particular pH. Considering that a large quantity of synthetic wastewater was needed, the decision was made to prepare saturated solutions of red lead oxide by lowering the pH of a quantity of deionized water to 6.0 with addition of nitric acid, and then adding a large quantity of Pb<sub>3</sub>O<sub>4</sub>. Laboratory analysis of samples of the supersaturated solution prepared in this manner showed that all had total lead concentrations in excess of 100 ppm, and a dissolved lead concentration of approximately 2 ppm.

Discussions with the manufacturers of each of the candidate compounds suggested that an empty bed contact time of 5 to 10 minutes would be desirable for optimum dissolved lead removal in a single-pass filter configuration. Two of the suppliers also preferred a filter bed depth of at least 3 feet. Consequently, an experimental apparatus was constructed consisting of three filter columns of  $\frac{3}{4}$  inch I.D. by 36 inches long, each fed from the bottom via Tygon tubing by a variable-speed peristaltic pump delivering test effluent to the media at a rate of 60 milliliters/minute (ml/min). The peristaltic pumps drew the synthetic wastewater from 3 liter Erlenmeyer flasks with the contents continually agitated by magnetic stir bars. Each of the columns was filled to within one inch of its top with filter media. The remaining volume was packed with a fine fiber glass wool to prevent loss of filter media out the top of the column. This apparatus was sized to produce an empty bed contact time of 5 minutes with the pumps operating at 60 ml/min. A diagram of the experimental apparatus is given below in Figure 1.

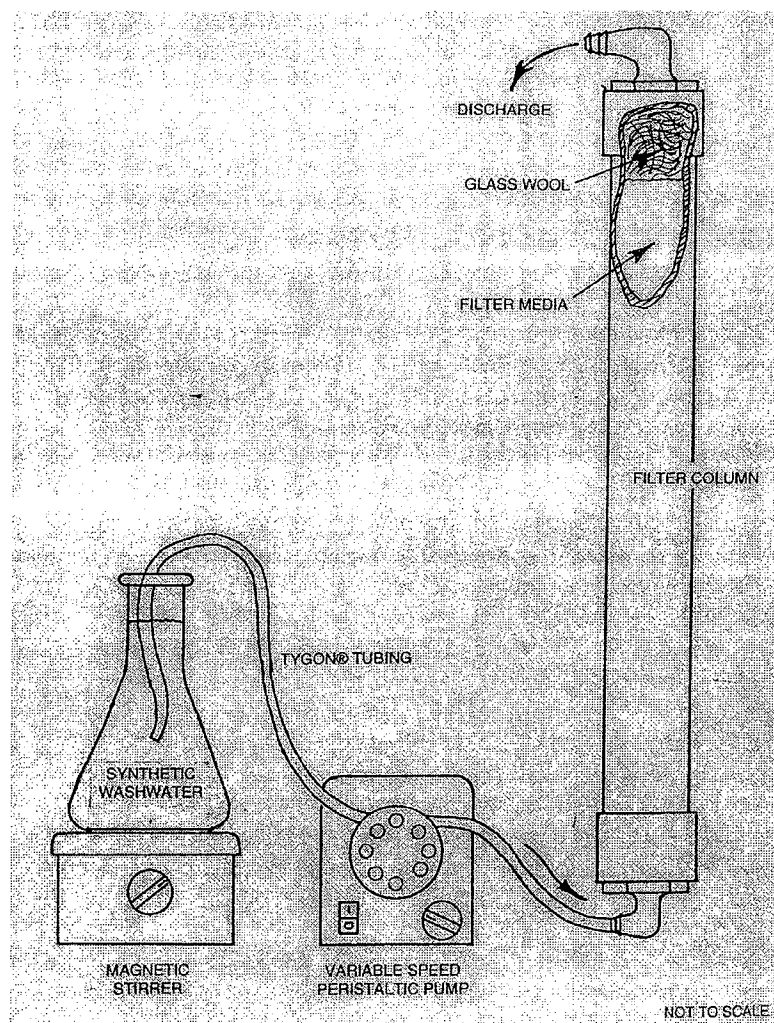


FIGURE 1 Experimental Apparatus Used to Evaluate Filter Media

Prior to the start of testing, each column was flushed at 60 ml/min for one hour with deionized water to remove any fine particles of media, and thereby condition the filter media for use. Grab samples of filtered solution were taken from the top of each of the filter columns at 5, 10, and 30 minutes following the start of the pumps supplying the columns. It was believed that 30 minutes would provide more than adequate time for the flow through the filter media to stabilize and become steady-state. SKJ Environmental Inc. of Atlanta, Georgia, analyzed the samples for both total and dissolved lead using Inductively Coupled Plasma Emission (ICPE) spectroscopy.

TABLE 1 Analytical Results from Laboratory Testing of Filter Media

Sample	Lead Concentration	
	Total (ppm)	Dissolved (ppm)
<i>Aqua-Bind EXP-300Z zeolite</i>		
unfiltered influent	119	2.13
discharge after 5 minutes	5.98	<0.050
discharge after 15 minutes	11.8	<0.050
discharge after 30 minutes	12.9	<0.050
<i>Fablite zeolite</i>		
unfiltered influent	119	2.13
discharge after 5 minutes	3.62	<0.050
discharge after 15 minutes	2.78	<0.050
discharge after 30 minutes	3.31	<0.050
<i>LEADX phosphate</i>		
unfiltered influent	580	2.01
discharge after 5 minutes	26.1	<0.050
discharge after 15 minutes	51.5	<0.050
discharge after 30 minutes	27.7	<0.050

## TEST RESULTS AND DISCUSSION

As illustrated above in Table 1, the analysis found that the dissolved lead concentration in every sample except for one was less than the 50 ppb practical quantitative limit (PQL) established for ICPE spectroscopy in SKJ Environmental's laboratory. Total lead concentrations were also substantially reduced by all three media, ranging from 2.7 to 52 ppm. The reason for the relatively high total lead concentrations found in the discharge from the *LEADX* filter was that the total lead concentration of the influent supplied to the column was itself nearly five times that supplied to the other two columns. Considered in terms of the percentage of lead remaining in the column discharge after 30 minutes had passed, all three media performed very well. The total lead concentration of the discharge from the column containing the *Aqua-Bind* zeolite was reduced to 10.8% of that entering the column; the *Fablite* zeolite reduced the concentration to 2.7% of the starting value, while the *LEADX* phosphate reduced the concentration to 4.8% of the starting value. The dissolved lead concentration in the discharge from all three columns was reduced to less than 2.5% of the starting value.

In summary, all three media performed very well in removing both total and dissolved lead from the synthetic wastewater. Although it was the desire of the project team to conduct additional bench-scale testing to establish the degree to which the lead binding or adsorbing capacity of each of the filter media degraded with continued use, the cost and time required to perform such a study was beyond the budget and time constraints of the project. In consideration of the degree of support and application data offered by their respective suppliers, the decision was made to proceed with field testing of the *Aqua-Bind* zeolite and the *LEADX* phosphate.

## FIELD TEST PROGRAM AND TEST RESULTS

### DESIGN OF FILTRATION SYSTEM

The project team met with Kentucky Transportation Cabinet officials in Frankfort, Kentucky, in March 2002 to discuss the results of bench-scale testing, consider conceptual designs of a full-scale prototype filtration system, and plan for field testing of the prototype in the summer of 2002. The participants agreed that based upon the bench-scale test results and the relatively low material cost, *LEADX* phosphate should be the primary media to be evaluated in field testing. Design of a prototype full-scale filtration system to evaluate the *Aqua-Bind* zeolite and the *LEADX* phosphate was aided by the fact that the suppliers' preferred filter system parameters (bed depth and empty bed contact time) were similar for the two compounds. The design was derived in part from analysis of data obtained by KTC from a number of bridge painting projects in Kentucky during the 2001 season.

In order to size the system, an assumption had to be made regarding the size of the bridge overcoating project upon which the system would be used, and thus what the maximum wastewater flow rate to expect. In the March 2002 meeting, KTC field engineers stressed the variable nature of the pressure washing duty cycle and pointed out that oftentimes only one pressure washer is at work on a bridge at a time. Because of this, the KTC engineers stated that they felt a process capacity of 400 gallons/hour would be adequate for medium-size bridge overcoating projects.

The resulting design for the filtration system was sized for mounting on a 16-foot tandem axle trailer for transport behind a ¾-ton pickup truck to the job site. A 5,000-watt portable generator was mounted near the front of the trailer to provide 120 and 240 volt AC current for driving the system pumps. Wastewater is pumped to the system from a sump pump immersed in the wastewater pooling on top of an impermeable tarp suspended beneath the bridge. The wastewater is held in a flow equalization tank, and then passed through a sand filter to remove larger suspended solids. The wastewater is then fed under pressure to a filter column; the filtered effluent exits the column and can be directed to another holding tank or into ground water, as desired. The system consisted of the following stages, described below; a photograph of the filtration system is shown as Figure 2:

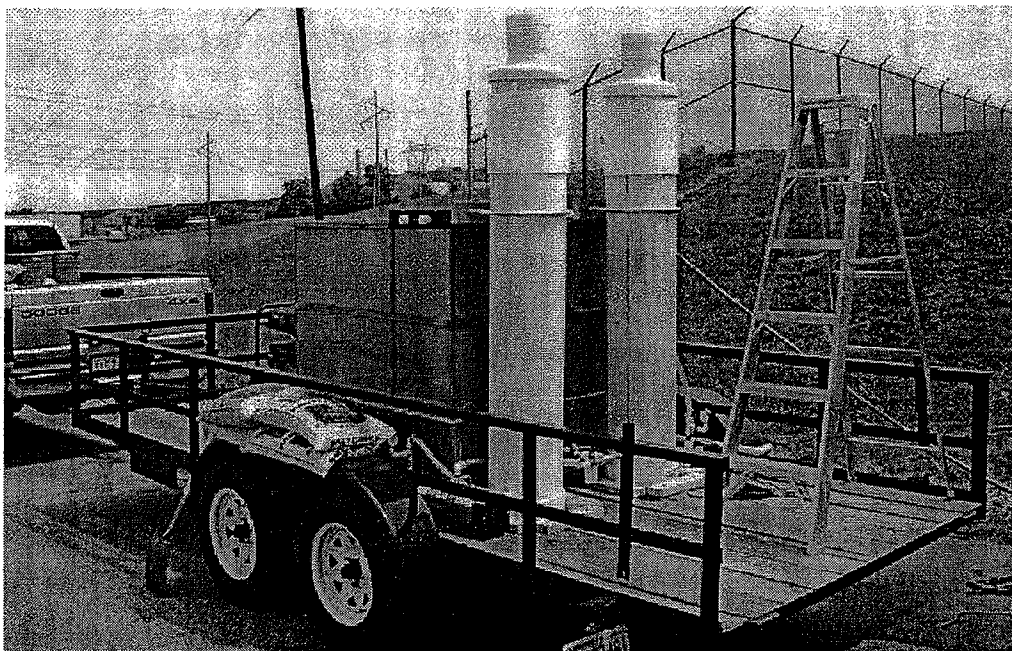


FIGURE 2 Prototype Filtration System as Tested

(1) Holding Tank.

In consideration of the cautions expressed by the KTC engineers regarding the variable nature of bridge washing operations, it was thought prudent to incorporate a holding tank of at least 30 minutes' capacity (200 gallons) as the first stage of the system. This holding tank would avoid the need for continually cycling the filtration system on and off to accommodate the intermittent flow of wastewater, and more importantly would permit steady-state operation of the various pumps incorporated in the system. Although all of the pumps used in the system are of self-priming design and capable of handling some entrained solids, none will tolerate continued running dry.

(2) Trickling Sand Filter.

Commonly accepted rules-of-thumb for the design of trickling sand filters for solids removal in municipal applications call for a minimum 30-inch deep bed with a flow rate of no more than 2 gallons/minute per square foot of surface area. A sand filter meeting these requirements was incorporated into the system in the form of a hybrid holding tank/sand filter. A large (4 x 4 foot) open-topped rectangular steel tank was partitioned into two compartments by welding a baffle in place across the height and width of the interior of the tank. The larger compartment served as the holding tank, and the smaller portion contained the trickling sand filter. Within the sand filter compartment, a 30-inch deep bed of filter sand (as used in swimming pool filters) was placed atop a 6-inch deep bed of medium gravel, which acted to minimize the amount of filter sand lost through the sand filter discharge port.

Wastewater was transferred from the holding tank to the trickling sand filter using a submersible pump mounted slightly above the floor of the basin (to minimize pump ingestion of large solids). The pump output was directed to a spray manifold mounted across the top of the tank above the sand filter. The spray manifold dispersed the wastewater across the top of the sand bed in order to evenly distribute the particle accumulation on the surface of the filter and thereby extend the service life of the sand bed. Figure 3 shows the top of the sand filter with the spray manifold in operation.

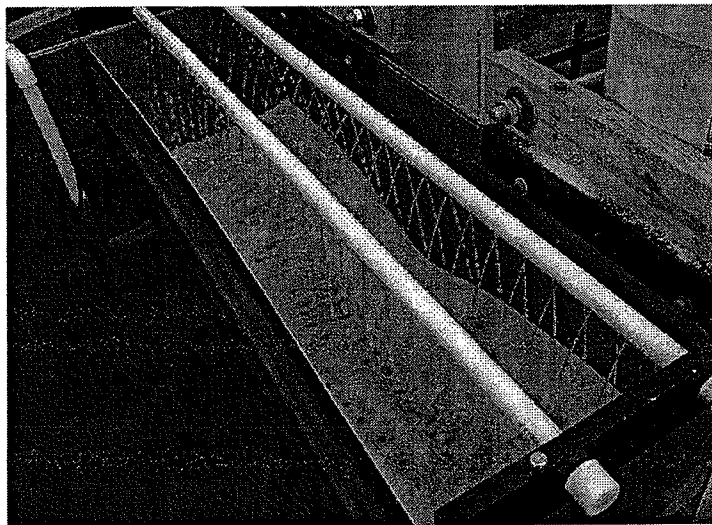


FIGURE 3 Trickling sand filter with spray manifold in operation.

Wastewater exiting the sand filter flowed first through a strainer and then into a distribution manifold of gate valves arranged so as to provide flexibility in directing the sand filter output to either or both of the filter columns, and to facilitate taking of grab samples from the sand filter discharge. The strainer was included to prevent any leakage of filter sand from flowing into and damaging the pumps feeding the filter columns.

(3) Phosphate and Zeolite Filter Columns.

The filter columns were constructed of 12-inch Schedule 40 PVC pipe and associated fittings, and fitted with a threaded pipe plug at the top to facilitate addition and removal of filter media. Each column was sized to accommodate the design flow of the system (400 gallons/hour). The columns were fed with self-priming centrifugal pumps. Filtered wastewater was discharged onto the ground from each column via a length of 3/4 inch flexible tubing attached to a nylon barbed nipple threaded into the side of each filter column. Figure 4 shows the distribution manifold, pumps, and filter columns.

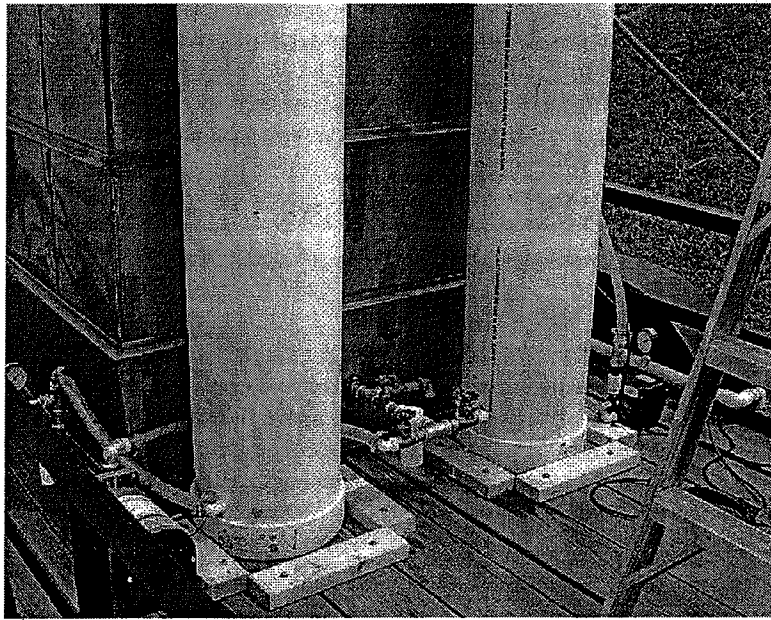


FIGURE 4 Distribution manifold, pumps, and filter columns.

Each column was prepared for use by loading filter gravel through the port at the top of the column so as to create a bed six inches deep, which was then topped with an appropriate amount of filter media, and then another six inches of filter gravel. The gravel beds provided a transition zone at the intake to prevent incoming flow from eroding cavities in the media, and another transition zone at the discharge to minimize loss of media from the column.



## FIELD TESTING IN OWENSBORO, KENTUCKY

### TEST PROTOCOL

The first opportunity to test the prototype filtration system came in June 2002, when a contractor began overcoating a small two-lane bridge near Owensboro, Kentucky. With the system positioned near the bridge, the contractor ran a hose from a sump pump on the containment tarp to fill the system's holding tank with wastewater at about five gallons/minute. The wastewater, generated by pressure washing at 7,000 psi, was dark brown in color and contained many large flakes of paint. As the holding tank approached being full, the sand filter pump was started to allow the footer space beneath the filter to fill with water. When this was accomplished, the pump feeding the zeolite filter column was started. After a delay of about five minutes, filtered water began pouring from the column discharge line. The discharge was initially tan in color, and gradually assumed the clear appearance of drinking water after about 15 minutes.

Water was passed through the zeolite filter column for a period of about 1.5 hours, and the grab sampling protocol described below was conducted during this time. At the end of 1.5 hours, flow through the zeolite filter column was stopped, and the pump feeding the phosphate filter column was started. The initial discharge from the phosphate column was somewhat cloudy with solids, but this rapidly improved to the appearance of drinking water after about 10 minutes. As with the testing of the zeolite column, a grab sampling protocol as described below was accomplished during the next hour of operation.

In order to quantify the filtration efficiency of the sand filter and the filter columns, the following sampling protocol was followed: At intervals of 30 minutes (sample #1) and one hour (sample #2) following the beginning of discharge from the filter columns, grab samples were taken of the unfiltered washwater, the discharge from the sand filter, and the discharge from the column. The samples of unfiltered washwater were taken from the water spraying from the spray manifold above the sand filter. Only one sample of sand filter discharge was taken, 30 minutes after the start of the zeolite filter column test run, as it was believed that this would adequately quantify what portion of the reductions in total suspended solids (TSS) and lead was being accomplished in the sand filter.

The collected samples were analyzed for TSS, total and dissolved lead concentrations, and pH by Microbac Laboratories Inc. of Louisville, Kentucky. Microbac Laboratories provided the analytical services for these and all other samples taken during the course of field testing. ICPE spectroscopy was utilized to determine lead concentrations. Table 2 shows the results of laboratory analysis of the grab samples taken during processing of washwater from the bridge washing work at 7,000 psi.

TABLE 2 Analyses of Water Samples Taken During Filtration System Testing at Owensboro, Kentucky  
Using Wastewater from 7,000 psi Pressure Washing

Sample	TSS (mg/l)	Lead Concentration		pH
		Total (ppm)	Dissolved (ppm)	
unfiltered wastewater #1	43	10	2.0	7.02
unfiltered wastewater #2	46	9.9	2.1	6.98
sand filter output #1	65	0.5	<0.1	7.47
zeolite filter output #1	554	<0.1	<0.1	9.20
zeolite filter output #2	617	<0.1	<0.1	9.17
phosphate filter output #1	59	<0.1	<0.1	7.64
phosphate filter output #2	44	<0.1	<0.1	7.63

Later in the afternoon on the day the filtration system was tested in Owensboro, the contractor increased the pressure washer output to 9,000 psi and directed his workers to spend more time washing each area of the bridge structure, in an effort to generate higher lead concentrations in the wastewater. As was done in the tests with wastewater from 7,000 psi work, the holding tank was filled with wastewater and the zeolite and phosphate filter columns were each operated for a period of about two hours. The discharge from each column was clear in appearance from the beginning and remained so for the duration of the test. A sampling protocol identical to that used during processing of wastewater from the pressure washing at 7,000 psi was used, with grab sampling being done at intervals of 30 and 60 minutes following the start of discharge from each of the columns. Table 3 details the results of laboratory analysis of these samples.

TABLE 3 Analyses of Water Samples Taken During Filtration System Testing at Owensboro, Kentucky  
Using Wastewater from 9,000 psi Pressure Washing

Sample	TSS (mg/l)	Lead Concentration		pH
		Total (ppm)	Dissolved (ppm)	
unfiltered wastewater #1	603	62	2.0	6.91
unfiltered wastewater #2	576	62	2.3	6.82
sand filter output #1	14	0.4	0.2	7.09
zeolite filter output #1	378	<0.1	<0.1	9.07
zeolite filter output #2	528	<0.1	<0.1	9.07
phosphate filter output #1	6	<0.1	<0.1	7.13
phosphate filter output #2	6	<0.1	<0.1	7.27

Due to a misunderstanding over the work order submitted with the samples collected during testing at Owensboro, Microbac Laboratories reported lead concentrations below 100 ppb as "<0.1 ppm", rather than giving the actual result to its full precision. Microbac assures a PQL of 3 ppb for lead analysis using ICPE spectroscopy, but only reports to this precision when specifically requested to do so. They were unable to retrieve the full precision data for the Owensboro samples from their equipment when the request was later made. Fortunately, the precaution had been taken of splitting all samples and holding part of each sample in refrigerated storage. Certain samples were then withdrawn from storage and subsequently analyzed for lead content, with the results to be expressed in ppb. Table 4 details the results of analysis of these samples.

TABLE 4 Analysis of Water Samples Taken During Filtration System Testing at Owensboro, Kentucky  
Using Wastewater from 7,000 and 9,000 psi Pressure Washing

Sample	Total Lead Concentration (ppb)
unfiltered wastewater (7,000 psi)	9430
zeolite filter discharge (7,000 psi)	170
phosphate filter discharge (7,000 psi)	3
unfiltered wastewater (9,000 psi)	9480
zeolite filter discharge (9,000 psi)	60
phosphate filter discharge (9,000 psi)	5

## DISCUSSION OF RESULTS

The cloudiness of the filter column discharges noted just after column startup was evidently the result of very fine media particles being flushed through, as it was not observed at any time after initial startup. In spite of recommendations from the media suppliers that the filter bed should be flushed with clean water prior to filtration, the field test environment made this impossible to accomplish.

It is evident that the trickling sand filter was responsible for a great deal of the overall reduction in lead content, by mechanically filtering out most of the larger paint particles. Flakes of primer and topcoat were observed on the surface of the filter bed at the conclusion of the day's test work. In the case of the wastewater generated by 7,000 psi washing, the total lead concentration was reduced from 10 ppm to 0.5 ppm, indicating a sand filter removal efficiency of 95%. The dissolved lead concentration was reduced from 2.0 to better than 0.1 ppm, also suggesting a removal efficiency of at least 95%. Sand filter performance was even more pronounced when processing wastewater from 9,000 psi washing, with the total lead concentration dropping from 62 ppm to 0.4 ppm, a removal efficiency of better than 99%. The dissolved lead concentration was reduced from an average of 2.15 ppm to 0.2 ppm for a removal efficiency of almost 91%.

The sand filter actually slightly elevated the TSS level of the water passing through it during the tests using wastewater from 7,000 psi washing, from an average of 45 mg/l to 65 mg/l. This phenomenon had disappeared by the time of the trials using wastewater from 9,000 psi washing, with the sand filter reducing the TSS from an average of 590 mg/l to 14 mg/l. It appears that the very finest sand particles contained in the filter sand were washed out of the bed in the initial stages of testing, leaving the bed conditioned for filtration use.

The data show that both filter columns acted as a polishing stage to further reduce total lead concentrations to the sub-ppm range. The phosphate filter outperformed the zeolite filter in this respect, reducing the total lead content of the wastewater from approximately 9.4 ppm down to approx. 4 ppb, well below the Federal drinking water standard. The zeolite filter was effective in reducing the total lead concentration down to 170 and 60 ppb using wastewaters from 7,000 and 9,000 psi washing, respectively. Although an order of magnitude greater than the results obtained with the phosphate filter, these lead levels are still acceptable for discharge to surface waters in many instances.

Two peculiarities are evident in the data for discharges from the zeolite column using wastewater from both 7,000 and 9,000 psi washing. In both instances, the TSS level of the discharge orders of magnitude greater than that of the incoming wastewater, and the pH of the discharge was somewhat elevated. Careful observation of the discharge from the zeolite column revealed that the source of the elevated TSS in the discharge was the zeolite media itself. The bed of relatively coarse gravel at the column discharge port was allowing particles of zeolite media to pass through. Subsequent bench-scale experiments with a 3-inch diameter test column in the laboratory using a zeolite column with a bed of very fine (1/8 x 1/16 inch) filter gravel at the discharge port eliminated the loss of media. The elevated pH of the discharge from the zeolite column was undoubtedly linked to some sort of chemical reaction involving the marble gravel beds at the top and bottom of the column, but the exact mechanism is not known.

## FIELD TESTING IN CADIZ, KENTUCKY

### TEST PROTOCOL

Project personnel availed themselves of another opportunity to test the prototype filtration system in July and August 2002, when a contractor began overcoating a two-lane highway bridge spanning a creek on U.S. 68 near Cadiz, Kentucky. This bridge was larger than the Owensboro test site, and consequently the project team had the opportunity to run several thousand gallons of wastewater through the system over the course of two weeks. It is important to note that the filtration system was moved from Owensboro to Cadiz without any attempt to clean the sand filter or to replace the media in the filter columns. In effect, the system began testing at Cadiz in much the same condition as it was in when work ended at Owensboro.

Work on the bridge was interrupted periodically by thunderstorms in the vicinity, or heat and humidity such that the workers doing pressure washing inside the containment area were overcome by heat exhaustion. Consequently, data was collected on three separate days. The operating and sampling protocol used in these trials was essentially the same as used at Owensboro, with grab samples taken at 30 minutes and one hour following the beginning of discharge from the columns. In addition, grab samples of the potable water being supplied to the pressure washer were taken. The motivation for this was to determine to what degree the chlorides content of the wastewater was elevated by pickup of chlorides from road salt and other sources, and to what degree, if any, the filtration system would reduce the chlorides level. Table 5 gives the results of laboratory analysis of grab samples taken on two different days while sections of the bridge were being washed at 4,000 psi.

TABLE 5 Analyses of Water Samples Taken During Filtration System Testing at Cadiz, Kentucky  
Using Wastewater from 4,000 psi Pressure Washing

Sample	TSS (ppm)	Lead Concentration		Chlorides (ppm)	pH
		Total (ppm)	Dissolved (ppm)		
potable water #1	<5	<0.01	<0.01	5	7.40
potable water #2	<5	<0.01	<0.01	15	7.41
unfiltered wastewater #1	396	21.8	0.863	130	7.32
unfiltered wastewater #2	371	22.7	0.831	125	7.32
sand filter output #1	11	3.47	0.573	105	7.22
sand filter output #2	16	3.50	0.642	120	7.46
zeolite filter output #1	23	1.11	0.379	120	7.62
zeolite filter output #2	25	1.15	0.383	125	7.61
phosphate filter output #1	<5	0.43	0.11	120	7.09
phosphate filter output #2	<5	0.44	0.13	125	7.10

Later in the project, the filtration system was operated on a day when a section of the bridge was being washed at a slightly higher pressure of 4,400 psi. Table 6 details the results of laboratory analysis of grab samples taken during this test run.

TABLE 6 Analyses of Water Samples Taken During Filtration System Testing at Cadiz, Kentucky  
Using Wastewater from 4,400 psi Pressure Washing

Sample	TSS (ppm)	Lead Concentration		Chlorides (ppm)	pH
		Total	Dissolved (ppm)		
potable water #1	<5	<0.01	<0.01	5	7.40
potable water #2	<5	<0.01	<0.01	15	7.41
unfiltered wastewater #1	270	13.8	0.314	125	7.30
unfiltered wastewater #2	290	16.9	0.309	110	7.32
sand filter output #1	10	2.15	0.672	125	7.52
sand filter output #2	11	2.17	0.675	125	7.51
zeolite filter output #1	18	0.367	0.138	125	7.65
zeolite filter output #2	24	0.376	0.136	95	7.65
phosphate filter output #1	<5	0.202	0.069	130	7.20
phosphate filter output #2	<5	0.215	0.066	125	7.20

## DISCUSSION OF RESULTS

The sand filter continued to be very effective in reducing TSS levels throughout the Cadiz trials. During the testing using wastewater from 4,000 psi washing, the sand filter reduced the TSS of the incoming wastewater by an average of 96.4%, from an average value of 384 mg/l down to 14 mg/l. The data from the trials using wastewater from 4,400 psi washing yielded similar numbers, with TSS being reduced by an average of 96.1% from an average value of 280 mg/l to 11 mg/l. The effectiveness of the sand filter in removing lead from the wastewater dropped slightly, with total lead being reduced by an average of 84.4% in the 4,000 psi trials and by an average of 85.9% in the 4,400 psi trials. The effectiveness of the sand filter in removing dissolved lead was much lower than in the Owensboro trials, with an average reduction of only 28.3% for the 4,000 psi data; to our surprise the data from the trials with wastewater from 4,400 psi washing show that the dissolved lead concentration actually rose, more than doubling from an average of 312 ppb to 674 ppb. The reason for this increase may lie in an inconsistency in the operation of the sand filter. Because the pumps which supply various stages of the filtration system were under manual control and did not deliver exactly the same flow rate, there were occasions when the pump feeding the filter column under test could not keep up with the pump feeding water to the sand filter. In these instances, the water level in the footer space beneath the sand filter rose up through the filter bed, flooding the bed. It is possible that the trickling sand filter then in effect became a fluidized bed, with paint particles now able to move more easily down through the sand bed. This could have freed paint particles previously trapped in the bed, and allowed them to exit the bottom of the filter, thereby elevating the dissolved lead concentration in the discharge.

The effectiveness of both filter columns in reducing total lead concentrations in the discharge from the sand filter continued to be excellent in the Cadiz trials, though slightly diminished overall from that seen in the Owensboro data. The total lead concentration in the sand filter discharge was reduced from an average of 3.49 ppm in the 4,000 psi trials to an average of 1.13 ppm (67.6% reduction) by the zeolite filter and to an average of 440 ppb (87.9% reduction) by the phosphate filter. The dissolved lead concentration in the sand filter discharge was reduced from an average of 608 ppb to an average of 381 ppb (37.3% reduction) by the zeolite filter and to an average of 120 ppb (80.2% reduction) by the phosphate filter. The total lead concentration in the sand filter discharge during the 4,400 psi trials was reduced from an average of 2.16 ppm

to an average of 372 ppb (82.7% reduction) by the zeolite filter and to an average of 209 ppb (90.3% reduction) by the phosphate filter. The dissolved lead concentration in the sand filter discharge during the 4,400 psi trials was reduced from an average of 674 ppb to 137 ppb (79.7% reduction) by the zeolite filter and to an average of 67.5 ppb (90.0% reduction) by the phosphate filter. As was the case in the Owensboro trials, the phosphate filter outperformed the zeolite filter in reducing both total and dissolved lead. The reason for the relatively poor performance of the zeolite filter in removing dissolved lead during the 4,000 psi trials (only 37.3% reduction) is not known.

The elevated TSS level in the zeolite column discharge noted in the Owensboro trials was not readily evident in data from the Cadiz trials. It can be postulated that the cessation of loss of media from the zeolite column was due to most of the smaller zeolite particles having already washed from the column, and the gravel bed at the discharge port of the column having become more tightly packed as a result of settling over time. In addition, the substantially elevated pH seen in the discharge from the zeolite filter column during the Owensboro trials was not noted in the Cadiz trials. The reason for this is not known.

The chlorides content of the potable water supplied to the pressure washer was raised from 5-15 ppm to 110-130 ppm by contact with the bridge surfaces in the trials. Processing through the filtration system had essentially no effect on the chlorides content of the wastewater. Given this, it would not be practical to recycle the discharge from the filtration system to supply the pressure washer unless an additional stage was added to address the problem. Although the ability to recycle bridge wastewater for continued use by the pressure washer would be very desirable in locales where the cost of trucking potable water to the job site is high, chloride contamination is the primary cause of coating failure on ferrous structures, and the elevated chlorides content of the system discharge would not be allowed by any highway agency coating specifications.

## CONCLUSIONS AND SUGGESTED RESEARCH

### CONCLUSIONS

Based on the results of the research in this study, the following conclusions are made:

- (1) *Aqua-Bind EXP-300Z* and *LEADX* are both effective as lead-binding media when employed in water filtration applications.
- (2) The prototype filtration system as tested on bridge overcoating projects in Kentucky performed remarkably well in removing both TSS and lead from wastewater contaminated with lead-bearing paint particles. The discharge from the filtration system was in many instances free of lead to the degree that it could safely be directly onto the ground or into surface waters.

### SUGGESTED RESEARCH

- (1) Determine the ultimate holding capacity of the filter media and characterize filtering efficiency over its service life. Any lead binding compound will eventually cease to remove lead after a given volume of contaminated wastewater has flowed through it, as a result of having reached a limit associated with its chemical ability to hold lead ions or having been coated with other contaminants which prevent the lead from contacting the media, or a combination of these mechanisms.
- (2) Determine the service life of the sand filter and devise less labor-intensive methods for servicing the filter.
- (3) Devise less labor-intensive methods for servicing the filter columns.

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