

Advances in the Science
of Heavy Metal Treatment;
Chemical Treatment/Crystallization

The MAECTITE® Process Description
and Case Study

Steven A. Chisick, CPG
Charles B. McPheeters
Chris K. Rice

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Sevenson Environmental Services, Inc.
8270 Whitcomb Street, Merrillville, IN 46410
(219) 756-4686

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Chisick, CPG., Charles B. McPheeters, Chris K. Rice
Sevenson Environmental Services, Inc.
8270 Whitcomb St., Merrillville, IN 46410
Tel (219) 756-4686
E-mail: SevensonMW@aol.com

Abstract

During the last several years advances have occurred in the practice of remediating toxic heavy metals in soil and other media. Pozzolanitic and silicic systems which attempt to entrap contaminants and chemical buffering systems which seek to minimize metal solubility by maintaining pH at artificially high levels are being phased out. Growing in use are chemical treatment/crystallization systems that incorporate heavy metals into durable, insoluble mineral crystal forms. The MAECTITE® process targets the formation of phosphate minerals, especially apatites. The hardness, chemical stability, thermal stability, and isomorphic properties of apatites make them ideal for reducing the leachability of metals. Since 1989, more than 700,000 tons of heavy metal contaminated soil, sludge, sediment, and debris have been successfully treated at over 50 sites using the MAECTITE® process. Advantages over other methods include cost savings, flexible application (exsitu, insitu, or in-line), regulatory acceptance, ability to handle both ionic and metals species (e.g. Pb, As, Cr, Cd, U, Sr), consistency of analytical results, longevity, improved leachability control, and in most cases, reduction in waste volume. This paper presents the evolution of the MAECTITE® chemical process and offers a full-scale study. The case study illustrates the removal of lead impacted soils from small arms target ranges at the Massachusetts Military Reservation. The authors believe that the advantages of chemical treatment/crystallization will establish it as the remediation method of choice for toxic heavy metals and radionuclides. MAECTITE® is a registered trademark and is patented by the USPTO.

Introduction

The solidification/stabilization of metals in hazardous waste has been implemented at remediation sites for more than 20 years. Solidification/stabilization is a viable tool for processing of various wastes, hazardous or nonhazardous, from commercial and industrial operations or historic sites with residue in contaminated media such as soil or water. Solidification/stabilization has evolved as the industry has advanced the learning curve to become more precise and sophisticated.

Ultimately, the naturally occurring fate of all pollutant material discharged by man to the environment is dictated by the relative thermodynamic stabilities of such material compared to the stability of possible other reaction products. For organic molecules the final products are CO₂, water, and oxyanions such as sulfates and phosphates. The end for heavy metal ions is incorporation in sediments/soils through precipitation as insoluble compounds such as hydroxides, hydrated oxides, oxides, sulfates, sulfides, and phosphates as well as absorption and adsorption phenomena.^{1,8,9}

Unfortunately, many of these natural changes take place slowly. The object of the MAECTITE® process is to accelerate these changes by exploiting chemical and geochemical principles and overcoming the slowness of some reactions. The general principle includes adjusting pH in conjunction with oxidation reduction reactions generalized in terms of removal of oxygen or other electronegative elements and addition of hydrogen or electropositive elements as a gain of electrons.^{5,9}

Since 1989 the MAECTITE® process has produced material reduced in metals solubility and leachability with improved handling characteristics. Post-processed material has been beneficially used in the reconstruction of firing range berms, left in various configurations onsite, and disposed of in Subtitle D non-hazardous landfills. Methods of application to contaminated media include insitu mixing, exsitu processing, and integration into waste generating manufacturing operations.

MAECTITE® produces a material with minimized solubility of heavy metals when exposed to pore water by the addition of reactive phosphates and sulfates, and, if necessary, addition of materials to alter raw material geochemical properties. Processed material also achieves performance standards based upon TCLP, SPLP, MEP,

ANS static leaching methods, as well as reducing bioavailability in contaminated soil/waste. The crystalline morphology of processed material includes metal-substituted hydroxyapatite and mixed-apatite-barite minerals, incorporating heavy metals into geologically stable forms which are less susceptible and available to impact the environment.^{4,6,7,9}

MAECTITE[®] uses the natural return of processed material to normal background pH by incorporating problem ions into apatitic structure along a sliding pH scale. Despite the importance of precipitation of apatite nucleated from solution as an amorphous meta-stable substance, the amorphous apatite rapidly converts into a stable apatite.⁷ There is still considerable uncertainty as to the nature of the phases formed in the early stages of the precipitation reaction under differing conditions such as supersaturation, pH, and temperature differences. Although thermodynamic considerations yield the driving force for precipitation, the cause of the reaction is frequently mediated by kinetic forces.⁵ The process works with the available energy flow, with nature, and not within temporary buffers.

The MAECTITE[®] process can be utilized on screened and unscreened firing range soil, can effectively reduce the leachability of metals laden soil washing residues, can process metal contaminated debris as well as a wide variety of soil types and waste matrices. This paper discusses the remediation of firing range soil for the National Guard Bureau (NGB).

Evolution of MAECTITE[®]

Since leaching of toxic metal constituents became regulated by USEPA for land disposal, responsible parties have sought more effective, innovative, and less costly methods to manage metal contaminated soil and debris. Early and still used practices of solidification/stabilization were primarily comprised of cement, pozzolans, and flyash additions to either solidify contaminated soil into a physically stable form resistant to leaching or to provide an alkaline environment resistant to leaching metals under USEPA's EP Toxicity (SW-846/1310) procedure.² Chemical techniques, such as MAECTITE[®], to reduce metal leachability and solubility were largely in development stages through the late 1980's.⁹ In 1990, USEPA modified the leach testing procedure defining toxicity with the promulgation of the TCLP procedure (SW-846/1311). Many alkaline treatment techniques which were successful in passing the EP Toxicity procedure for RCRA metals were unsuccessful in passing the more stringent TCLP procedure, particularly alkaline reagent additions.³ To be successful cements need to precipitate calcium salts and historically have emplaced problem ions in high alkaline states that temporarily buffer their presence. As the cement cures the calcium salts precipitate and complex with the resultant drop in pH. The problem ions may again become mobile producing TCLP failure as the pH normalizes.³

Today chemical stabilization systems have risen to capture a significant share of the metals stabilization market given a number of benefits resulting from these techniques. "Stabilization" techniques today still include cement and pozzolan blends with and without performance enhancing additives, but also include sulfide additions, liquid silicate additions, granular phosphate additions with and without performance enhancing additives, and liquid phosphate source additions with or without performance enhancing additives.^{2,9}

Application of the MAECTITE[®] process has likewise evolved to become more efficient and cost-effective since full-scale activities commenced in 1989. Advancements include addition of an in-house treatability laboratory, reagent source selection allowing soluble phosphate and sulfate in a single field application, utilization of in-place application and mixing methods, the development of seasoned project management, field supervision, and field labor coupled with a large inventory of company owned equipment.

Case Study - Massachusetts Military Reservation

Background

USEPA Region I issued an Administrative Order directing the National Guard Bureau (NGB) to perform remediation activities and address potential impacts of lead at Massachusetts Military Reservation firing ranges, Cape Cod, Massachusetts. Normal range operations were suspended pending management of these impacts. Among the immediate remediation options under consideration by the NGB was a multi-phased site characterization, soil washing research and development effort, followed by pilot-scale soil washing. In this approach affected ranges existing at the site would be placed under an impermeable cover while the site was

characterized and the soil washing system was developed, designed, and deployed for full-scale operations. This method would have required a lengthy period to plan and implement, and faced considerable technical obstacles. Another alternative under consideration included an expedited characterization of the firing range berms followed immediately by remediation (See Figure 1). This approach planned for soil to be removed and screened for visible spent projectiles. The soil generated from this screening were then processed using MAECTITE®. Impacted soil without visible bullet fragments would be processed in-place using MAECTITE® and left in the berm configuration without screening. Processing of the berm soil in this approach would be complete within 90 days of characterizing any particular berm.

NGB selected the approach offered by Severson and a team was formed by the NGB which included Severson Environmental Services, Inc. and Ogden Environmental and Energy Services as NGB's Supervising Contractor. This team negotiated on behalf of the National Guard Bureau with the regulating community, developed a comprehensive range characterization plan and an expedited remedial response to address lead from 16 small arms firing ranges. This allowed the Massachusetts Military Reservation to continue as an active training facility for the National Guard Bureau.

Pre Excavation Activities

Sixteen impacted firing ranges were addressed in the range maintenance effort under the workplan approved by USEPA Region I and the Massachusetts Department of Environmental Protection (MADEP). These ranges were designated as A, B, C, D, E, F, G, H, I, J, K, KD, N, O, P, SE, and SW. Pre-excavation activities can be described as consisting of four essential elements: berm survey, sampling, excavation analysis, and data collection/interpretation. Mobilization of equipment and personnel was phased with the requirements of the ongoing tasks. All equipment to perform field excavation and material processing set-up onsite by 27 February 1998.

1) Berm Survey

The berm survey consisted of a pre-excavation survey to obtain baseline elevation and to establish field markers to be utilized during sampling and excavation activities. A baseline estimate of lead impacted material was made to develop a budget for the NGB at this time. Preliminary estimates were 28,000 tons of impacted material requiring exsitu processing and an additional 13,500 yd³ requiring insitu processing. Coupled with post-excavation surveys, volumes of material excavated and processed insitu were calculated for each of the sixteen ranges using an average end area method.

2) Pre-excavation Sampling

Pre-excavation sampling crews mobilized and began collecting samples on 16 February 1998. Pre-excavation sampling was based upon collecting discrete samples at 25' intervals extending laterally across the berm surface originating at the center-point of each berm. Per the approved sampling plan, samples were collected using a bucket auger or with a truck mounted hydraulically driven push sampler. Difficult conditions encountered at the site proved to be obstacles for effective and efficient sampling at depths in excess of 2-4'. Of note, were steep slopes of some berm configurations and aggregate encountered ranging from 2-5" nominal diameter. With the cooperation and approval of EPA's onsite representative, the sampling method was modified to include the use of trenching with an excavator. Samples were collected at 2 foot depth intervals perpendicular to the face of the berm, and in 2' vertical increments at the toe of the berm. Initial sampling depths extended to 6'. This pre-excavation sampling process was applied at all of the ranges beginning with ranges G, H, K, KD, and O. When results indicated TCLP lead was in excess of the performance goal of 5.0 mg/L TCLP lead in the 4-6' interval, sampling crews gathered additional pre-excavation samples at 2' intervals until analytic results confirmed material was not impacted by firing range operations.

3) Pre-Excavation Analysis

Analysis of pre-excavation samples was carried out utilizing both onsite and offsite laboratories. In all 1,125 pre-excavation samples were collected of which 821 were analyzed onsite with the remaining 304 analyzed offsite. Parameters for the onsite laboratory were TCLP (mg/L) and total lead (mg/kg). In addition, 96 duplicates samples

were analyzed at an ACOE certified offsite laboratory. QA guidelines required 10% of the samples collected be analyzed at the ACOE approved laboratory to assure the quality of the onsite lab. As required by the Environmental Protection Agency, these samples were analyzed for total, Sb, Cu, Ni, and Fe as well as total and TCLP Pb.

Of the 264 samples collected from ranges G, H, K, KD, and O, 248 were analyzed offsite by the ACOE approved laboratory. As expected, TCLP lead was variable and ranged to 734 mg/L in pre-excavated soil.

4) Data Collection and Interpretation

Data collected was then transposed from laboratory sheets to graphical representation for each of the firing ranges. These graphs reported data representing both the lateral and vertical extent of affected soil. In addition, visual determinations of lead by a USEPA onsite representative were used as a guide for excavation limits.

Excavation, Processing, and Reconstruction Activities

Excavation Operations

Excavation, loading and transportation operations commenced at range G on 27 February 1998. All excavation operations were completed 11 June 1998. In all, 17,788 yd³ of impacted soil was excavated, loaded, and transported to a central exsitu processing facility where the soil was screened to remove spent bullets/bullet fragments. The resulting range soil was processed chemically using MAECTITE[®]. Existing passageways to the ranges were repaired and improved as necessary to provide reasonable and safe access and to eliminate the potential to generate dust from transportation operations. In addition to exsitu processing, 5,380 yd³ of impacted berm material was processed insitu using MAECTITE[®].

Based upon their historical use the presence of UXO was not predicted at the ranges. However, during excavation operations at Range I, a suspected UXO was encountered. The National Guard Bureau tasked MAANG 102 Explosives and Ordnance Demolition (EOD) to sweep the ranges for UXO. Three delay days were required for EOD to complete the sweep. One unexploded luminary round was destroyed in-place by EOD. Other suspected UXO were determined to be spent dud fin rockets and a spent rocket propellant unit.

The excavation work zone and contaminant reduction zone was established at the range excavation sites using roped barricades with attached warning signs. Excavation proceeded in accordance with each specific range's excavation plan in the 25' laterally spaced transecting planes across the face of the berms. Excavation was predominantly limited to the top two feet of the berm surface, but extended to 18' at one berm and in excess of 8' at three additional berms. Deeper excavations were attributed to historical refacing of the berms. Excavation productions were logged daily for each of the 16 berms. Material was either loaded directly into tandem axle dumps or stockpiled at the toe of the berm before being transported to the central processing area. All tandems were tarped. Air monitoring stations were established both upwind and downwind of the excavation areas. Water misting sprays were used as necessary at the excavation sites and the central processing areas. Dust was also controlled using a water truck and spray bar on haul roads to and from the central processing areas. Throughout the project dust was effectively controlled and no upgrades in respiratory protection were required.

Post-excavation sampling was completed at the bottom of the excavations within the berms to confirm that lead was removed to less than the project performance objective of 5.0 mg/L TCLP lead. In all, 286 discrete post-excavation samples were collected and analyzed for total and TCLP lead. Thirty-one of these samples were sent offsite as duplicates for quality assurance. All of the final post-excavation bottom samples were confirmed less than the performance criteria of < 5.0 mg/L TCLP lead.

Processing Operations

Exsitu Processing

Operations for excavated range soil were established at a central exsitu area located in proximity to the range control command post. This area also served as the lay down area for Severson's mobile laboratory, project management trailer, equipment/tool trailer, decontamination station, and other project support equipment. Construction fencing restricted access to the area and delineated the exclusion and contamination reduction zones.

Excavated and transported range soil was placed in a central stockpile and fed into an exsitu processing system. Material was pushed by a dozer and then handled by a tracked excavator which loaded material into a bar screen/shredder (6") where oversized material was removed for batch processing. Material passing through the 6" screen was then conveyed to a "stacked" screening plant consisting first of a 2" screen and then a #4 screen (0.187" nominal diameter). Material rejected at the 2" screen was directed to an oversized stockpile. Approximately 300yd³ of rejected material diverted as oversized material was batch processed with MAECTITE[®] and returned to the site. Material rejected at the #4 screen was composed primarily of small stones, bullet fragments, and bullets. This material was conveyed and stockpiled separately to await recycling for metal content by others.

Material passing through the #4 screen was then conveyed by a weigh-belt into a pugmill mixer where MAECTITE[®] chemicals were metered, added, and mixed into the soil. Soil was discharged and accumulated in 500 tons stockpiles. All post-processed material stockpiles attained the performance criteria of <5.0 mg/L TCLP Pb. 96% of the post-processed material measured < 0.50 mg/L TCLP lead. Production averaged approximately 500 tons/day with the highest daily production being 1,300 tons. A total of 27,952 tons of screened soil was processed with MAECTITE[®]. Exsitu production began on 6 March 1998 and was completed on 15 June 1998.

Insitu Processing

The criteria for excavation and exsitu processing was the presence of visible lead either during pre-excavation sampling or visual determination by USEPA's onsite representative during actual excavation operations. When visible lead was no longer apparent, bottom post-excavation sampling analysis was then conducted for confirmation. If the bottom sample was measured at > 5.0 mg/L TCLP lead, then insitu MAECTITE[®] processing occurred in these areas. Insitu processing consisted of application of liquid MAECTITE[®] chemicals to the impacted material, followed by mixing with a tracked excavator. Post-insitu samples were then collected to confirm TCLP lead had been reduced to less than 5.0 mg/L. In all, approximately 5,300yd³ of berm soils were processed insitu at an average daily production rate of approximately 200yd³/day. Insitu processing began on 19 March 1998 and was completed on 8 June 1998. Twenty-nine post-insitu samples were collected and analyzed to confirm conformance with < 5.0 mg/L TCLP lead criteria. All samples attained the performance criteria, with 97% of these samples measuring < 0.50 mg/L TCLP lead.

Berm Reconstruction and Demobilization

After the NGB and Supervising Contractor (Ogden) reviewed analytical data from soil processed exsitu, approval was given and Severson commenced reconstruction of two firing range berms to the original contours based upon the pre-excavation survey. After this task was completed, equipment was decontaminated and demobilized. All equipment was removed from the site by 2 July 1998. Reconstruction of the remaining ranges using processed soil from the exsitu system will be completed by base contractors.

The project was completed five weeks ahead of schedule despite (18) days of delay due to weather and UXO clearance activities. The National Guard Bureau fully complied with the terms of the administrative order issued by USEPA Region I in an effective, timely, and responsible manner.

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FIGURE 1
DECISION FLOW DIAGRAM
MMR Range Maintenance Project, Cape Cod, MA

