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Research Reveals Characteristics of Ferrous Foundry Wastes

A 17 year research project concludes that foundry wastes are no serious threat to underground water and they do have potential for highway construction.

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For nearly two decades, the American Foundrymen's Society has funded a research project supervised by the University of Wisconsin (UW) Department of Civil and Environmental Engineering at Madison involving the disposal of foundry process solid wastes. This article is an overview of the results of that important investigation.

Initial Needs Concept

Despite the apparently successful and widespread use of foundry waste for fill and land reclamation, there was industry concern about the environmental implications of land disposal of foundry wastes. If shown to be a problem, disposal of these wastes could result in increased regulatory pressure, liability issues and difficulty in obtaining future disposal sites.

This prompted the AFS Committee on Water Quality and Waste Disposal (10-F) to investigate constructive use of foundry wastes in sanitary landfills, fill material in natural or constructed depressions and road construction. With little research at hand, the Committee requested that UW develop a plan.

The resulting plan was divided into three phases:

Phase A—Identification of wastes types and any special properties of those wastes affecting proper disposal, including a study of the leaching characteristics of the wastes, development of a standard foundry waste leaching test for characterizing wastes and test results.

Phase B—Pilot scale leaching testing under simulated field conditions, investigating the effects of rainfall, infiltration, climatic cycles and physical waste properties.

Phase C—Testing of existing foundry landfills and/or large-scale test landfills to determine the ability of laboratory leaching test methods to predict field leaching.

The three phases have been completed and are reviewed in this article. Additional work related to using foundry wastes in highway construction, though not part of the original concept, also is discussed.

Research Results[1,2]

At the beginning of Phase A, little was known about typical foundry wastes. A study was made of different foundries to perform material balances of the raw materials in use and to track these materials into various waste products leaving the foundry. This work looked in detail at the sources of foundry process wastes, identifying the characteristics and quantities of waste from each source.

Table 1, a summary of the results, indicates that the largest amount of waste leaving a foundry is usually system sand.

Foundry wastes in a landfill are exposed to precipitation that works down through the waste, leaching or dissolving soluble constituents from the waste and possibly contaminating the groundwater. Groundwater contamination was believed to be the major environmental concern regarding land disposal of foundry wastes.

A leaching procedure was developed to study foundry waste leaching characteristics. The concept was to mix samples of the waste and water for a prescribed period, separate the resulting liquid and analyze it. Several test parameters that would affect the results were established. These included:

- Time: Mixing time had to be short enough so that the test could be run in a practical length of time, yet long enough to obtain realistic results;
- Amount of solid waste used: The amount of solid material used had to be small enough to be workable in a laboratory situation, but not so small that the results were statistically unreliable.
- Amount of liquid: If the amount of liquid was too small for a given amount of solids, the results would have been solubility-dependent, masking differences between wastes. If too much liquid was used, the concentrations of some components would have been so low as to be unmeasurable.
- Liquid composition: Distilled (or ionized) water was used in the test because it closely simulates rainwater. The water soon took on characteristics derived from the waste.
- Batch or shake flask test vs. column test: The flask method was selected because it is faster, more reproducible and liquid can be obtained for analysis. Many foundry wastes are so impermeable that it is difficult to obtain water from column tests in required amounts in a reasonable time.
- Waste preparation: Large items, such as core butts, clearly could not fit into most laboratory flasks. Therefore, large pieces were cut to manageable size and sampled correctly to provide defensible test results.
- Number of elutions: Each elution corresponded to one prescribed mixing period with the same liquid and solid materials. Preliminary experiments determined that three elutions (three volumes of liquid, but the same solid sample) normally characterized dissolution patterns. More elutions provided little additional information, and fewer gave no indication whether a given parameter was likely to leach out at the same rate over a long period of time or drop off markedly upon further leaching.

The testing procedure ultimately produced is believed to be the first published test developed to examine the leaching characteristics of a specific waste. It is now referred to as the AFS leaching test.[1]

The leaching test was used to evaluate a variety of wastes generated under different conditions. The results indicated that the raw materials entering the foundry and the binder system are particularly important in determining waste leaching characteristics. It was also determined that waste leaching characteristics depend on particle size, so that core butts produced less leachable contaminant per unit weight of waste material. Finally, it was found that subjecting waste to higher temperatures results in less organic matter leaching from the waste.

Phase B[1]

The concept of this phase was to set

up a series of small test landfills to be subjected to the climate of southern Michigan, an area with a weather pattern typical to much of the foundry industry. Daily climatic variations were accelerated so one could simulate in the laboratory one year in only four months. Test landfills measured two square feet by one and one-half foot deep.

A second part of Phase B involved a detailed examination of the water flow though foundry process solid wastes, especially under saturated conditions. Intermittent precipitation at a landfill's surface produces variation in moisture content of the waste, especially near the surface.

Unsaturated conditions result in lower permeability values than would be expected under saturated conditions and can affect the downward flow of moisture and the waste-moisture contact. It was considered important to evaluate this effect in comparing laboratory leach test and lysimeter data.

Phase B results indicated that foundry processes produced wastes with widely different leaching characteristics, in agreement with the results of Phase A. Therefore, it was not possible to classify all foundry process wastes as representing equal threats to groundwater quality.

The results also showed that the AFS leach test did indicate qualitatively the species likely to be leached from the wastes tested in the small landfills.

Further, the AFS test was more aggressive, resulting in higher concentrations than obtained in the test landfills. This suggests that the AFS test concentrations also would be higher than those observed in an actual landfill. Less than 30% of the matter eluted by the AFS test was generally eluted in the one-year landfill simulation, per unit weight of waste.

It also showed that the mixing of wastes gave leaching results similar to what would be calculated if the wastes were leached separately and the results combined in proper proportions.

Finally, the laboratory landfills indicated that sloping foundry waste landfills minimized leaching. The sloping results in more runoff, which reduced the amount of moisture flowing downward through the waste, leaching materials from the waste and potentially contaminating groundwater.

Emission Control Dusts & Sludges[3]

In 1979, the EPA proposed adding lead/phenolic sandcasting waste from malleable iron foundries to the hazardous waste list. In 1980, EPA proposed adding lead-bearing wastewater treatment sludges from gray iron foundries. The potential effect of such listings to the industry prompted AFS to develop a program with EPA to provide a much broader data base to help EPA decide whether or not to define these wastes as hazardous.

The resulting joint project was to sample wastes from numerous foundries and subject them to leaching procedures to determine if the wastes were hazardous according to the then published EPA hazardous waste criteria.

The concept involved studying cupola dusts and sludges as well as mixed foundry process solid wastes, since co-disposal of these mixtures was commonly practiced.

All of the foundries sampled were selected by EPA's Office of Solid Waste. The EPA or its contractors collected and shipped samples to UW and EPA's own laboratory for independent EP (extraction procedure) testing—the process then used by EPA to characterize wastes as hazardous.

A distilled water extraction procedure was performed at UW to more closely simulate actual landfill conditions. The university also tested for total metal content to determine the portion of each metal actually leached from the wastes under the two leaching procedures.

The university's specific objective was to provide laboratory extraction testing for cadmium, chromium and lead in emission control wastes from cupola, electric arc or induction furnaces in gray iron foundries, using both the EP and water leach tests. In addition, the total concentrations of these metals were determined for comparison with the extracted amounts. Effects of mixing emission control wastes with other foundry solid wastes also were evaluated.

The conclusions revealed that the EP extraction and analytical test procedures were reproducible for duplicate samples at the UW laboratory and between the UW and EPA laboratories. Results showed cupola dusts or sludges from nine of 21 foundries sampled were EP-toxic.

The wastes from two foundries were cadmium-toxic only, three were lead toxic only and four were both cadmium- and lead-toxic. None was chromium-toxic. Cadmium and lead extraction was highly dependent on solution pH. Using the EP procedure, but with distilled water instead of the acetic acid solution, the cupola dusts or sludges from only one foundry were EP-toxic with cadmium concentrations.

Cupola dusts and sludges containing particles, visually classified as very fine, were more likely to be EP-toxic than coarser particles. Toxicity effects of cupola dusts or sludges were diluted by mixing with other foundry wastes so that a given foundry's mixed wastes were much less likely to be EP-toxic than were the original cupola dusts or sludges. The mixed waste from one foundry was cadmium-toxic and mixed wastes from two others were lead-toxic.

The EP-toxic dusts or sludges generally contained relatively large amounts of the metal in question. However, wastes containing large amounts of a given metal were not necessarily EP-toxic with respect to that metal. Thus, a waste's metal content did not relate directly to that metal's availability in the EP test. The percentage of a given metal present in a waste released in the EP test ranged from 0 (not detectable) to 39% for cadmium, 1-12% for lead and 0-0.5% for chromium.

Finally, the foundry processes most likely to produce EP-toxic cupola dusts or sludges were electric arc furnaces and/or baghouse wastes. This is probably the result of such wastes tending to be finer and more acidic than wastes from other processes tested.

Phase C

Phase C's original concept was to complete sequential testing ranging from laboratory scale leach tests to laboratory scale model landfills to full-scale monitoring of actual landfills.

However, by the time Phase C was accomplished, an additional concept was included. This was an attempt to correlate the leaching characteristics of foundry wastes in the field with the objective of determining whether special landfill criteria could be established and justified for the disposal of only foundry process wastes.

These are the so-called mono-landfill criteria used to evaluate the impact of foundry waste landfills on groundwater quality, support mono-landfills and ascertain the suitability of wastes for construction purposes.

Inorganics Study[4,5]

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was the joint effort of UW and RMT, a consulting eingineering firm. The university was to study waste leaching characteristics using batch leaching tests and unsaturated zone sampling at existing foundry waste landfills.

The EPA extraction process (EP) test and a similar deionized water procedure, termed the EP-water test, were run on freshly generated foundry wastes mixed according to the waste percentages generated at each foundry to determine the leaching characteristics to be expected at each landfill.

Similar leaching tests were performed on individual waste components to determine the pollutant generation potential of each component.

Leaching tests also were run on auger samples obtained while installing pressure/vacuum lysimeters in the landfills. The auger cuttings were leached to investigate the variability of leaching characteristics within a landfill according to changes in waste composition and the localized microenvironment of each lysimeter.

The results of laboratory batch leach tests on auger cuttings were then compared to leachate samples obtained from the unsaturated zone of the various foundry waste landfills. It was believed that such a comparison would provide the best indication of the ability of laboratory leaching tests to predict field values.

The university studied six foundry landfills with the pressure/vacuum lysimeters, plus data from a seventh, the latter operating a leachate collection system at its landfill and its leachate periodically analyzed.

UW selected foundries that had not significantly changed their production processes during the period of generation of the wastes placed in the tested landfills. All landfills contained only foundry wastes.

RMT leachate characteristics studies used three-batch leaching tests and saturated zone (groundwater) sampling at seven foundry landfills to gather data from waste characterization and analysis studies, as well as hydrogeological investigations of the landfills.

This work concluded that leachate from the unsaturated zone of the six landfills the university studied had relatively low concentrations, with respect to drinking water standards, for all contaminants except iron, manganese and fluoride.

Manganese and iron, which are secondary parameters, exceeded the drinking water standards in the majority of leachate samples from all six foundries. Fluoride exceeded the drinking water standard (1.4 mg/liter applicable at the time of the study) in the majority of samples from three foundries.

The nonhomogenous nature of foundry wastes and landfills significantly affected leachate quality, leading to highly variable water quality, depending on sampling point and time. The university determined that leach tests on auger samples of wastes were more accurate in predicting field leachate composition than leach tests run on raw composite wastes.

The results of the RMT study, emphasizing groundwater quality, indicated that of the seven ferrous foundry landfills studied, none contributed amounts greater than the drinking water standards for arsenic, cadmium, chromium, lead mercury, selenium or silver.

Contribution is defined as the increase (if any) in the concentration of the drinking water element between

*Table 1. Estimated Pounds of Material Leaving Foundry by Category Per Year***

Foundry	Malleable I	Ductile Iron II	Copper Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	200,200	728,100	52,900	530,000	974,300	32,122	130,344
B. System Sand							
1. Molding Sand from New Material	1,924,100	23,600,000		20,351,600	16,467,900	69,000	
2. Degraded Shell	195,300	6,623,200		382,000	228,500		
3. Other Degraded						615,000	
4. Degraded CO_2	617,600			570,000		443,000	
5. Degraded Oil	503,000			3,226,700	2,938,800		
6. Degraded No-Bake				751,000			
Subtotal	6,240,000	30,222,200	3,544,500	25,281,600	19,635,200	1,127,000	342,000
C. Core Sand Total							
1. Core Butts	1,315,900	1,168,800	280,000	4,929,900	3,167,200	3,777,000	270,000
2. Core Room Sweeping	250,000	260,000	2,040,300	1,790,400	712,800	50,000	200,000
Subtotal	1,565,900	1,428,800	2,320,300	6,720,300	3,880,000	3,827,000	470,000
Total Sand	7,805,900	31,652,000	5,864,800	32,001,900	23,515,200	4,954,000	
D. Annealing Room Waste	200,000						
E. Cleaning Room Waste							
1. Grinding	13,800		22,400	29,300	88,600	1,000	1,507
2. Steel Shot	49,100		12,000	206,000	48,800	23,400	91,800
3. Other	5,400		60,000	6,000	1,777,800		
Subtotal	68,300	1,205,900	94,400	251,300	1,915,200	24,400	93,308
F. Slag	480,000	5,460,000	**	7,968,000	2,488,000	**	**
G. Coke Ash		8,672,000		21,516,000			
H. Scrubber Discharge				1,032,000			
I. Dust Collector Discharge	100,000		52,000	4,800,000	200,000		
J. Miscellaneous	25,200		65,200		35,500		
TOTAL	8,899,600	47,718,000	6,129,300	68,098,600	29,128,200	5,010,522	1,035,652

*Does not include cast products or gaseous wastes.
**Annual tonnages of dross returned to smelter not reported.

upgradient and waste boundary downgradient wells. One landfill added barium and mercury to groundwater by an amount near or over the drinking water standards for these elements at waste boundary or outside waste boundary wells.

The landfills added several secondary drinking water parameters to groundwater at these wells, primarily iron, manganese, total dissolved solvents (TDS) and sulfate. When phenols and the primary drinking water metals were found in the saturated wastes groundwater, they were rapidly attenuated at the boundary or near boundary wells.

The EP test on waste components indicated that for three foundries, the melting furnace emission control waste was EP-toxic for cadmium and lead; in none of the three cases was the metal classifying the waste as EP-toxic found in the saturated waste or waste boundary groundwater.

Results of the RMT and UW research demonstrated that the relationship between leach tests and field leaching is complex and that chemical and physical influences on leaching in both laboratory and field testing need to be understood before extrapolating laboratory test results to the field.

When run on composite waste samples, water leaching tests (including the AFS test) often overestimated primary drinking water metal groundwater concentrations, but underestimated groundwater concentrations of very soluble or redox-sensitive parameters such as iron or manganese.

Waste Variability Testing[6]

During Phase C research, it became evident that waste variability made it difficult to draw conclusions regarding individual wastes and the quality of saturated zone leachate within the field landfills, as well as in the groundwater quality surrounding foundry waste landfills.

Thus, an additional effort was made to test a large number of samples from one foundry to better assess the variability of foundry waste leaching characteristeics compared to the landfill unsaturated zone leachate quality.

The first objective was to estimate the leachate quality variability introduced by sample preparation, leaching and analysis for each of three waste sources obtained from a single ferrous foundry (i.e., baghouse dust, system sand and core butts).

Baghouse dust was selected because it usually contains the most significant concentrations of leachable heavy metals; system sand was selected because it is typically a foundry's major waste; and core butt waste was selected because it was considered the most difficult material to sample. Two leaching procedures were used: EPA's EP-toxicity using acetic acid and a similar procedure using deionized water (the EP-water procedure).

The second objective was to estimate the leachate variability over time for each of the three waste types using the same two leaching procedures The third objective was to compare the leach test results to leachate quality in the unsaturated zone of the landfill containing only waste from that particular foundry.

"Baghouse dust... usually contains the most significant concentrations of leachable heavy metals"

The conclusions indicated that for the chemical parameters evaluated, the variability introduced by the laboratory sample handling leaching and analytical procedures produced about a 50% coefficient of variation (standard deviation expressed as a percent of mean).

This variability was equal for both the EP and water leaching procedures. Of ten chemical parameters investigated during a two-month sampling period, there was nearly equivalent time variability in leaching quality within each of the three waste sources as evaluated by the two leach tests. Generally, the foundry process variability affected the waste types similarly.

It also was concluded that more iron, manganese, zinc and phenol were leached from the baghouse dust samples than from core butts or system sands, and that the EP leaching procedure extracted more of these parameters from the baghouse dust samples than did the water leaching procedure.

The results also indicated that more cyanide and fluoride were leached from the baghouse dust samples, but the two leaching procedures were comparable for extracting these parameters from the baghouse dust samples. Most analyses for cadmium, chromium and lead were below the analytical detection limits.

Both EP and water leaching procedures varied in their ability to predict landfill leachate concentrations. The EP procedure produced better predictions for manganese and possibly iron; the water leaching was better for copper and zinc. Procedures' were basically equivalent for cadmium, chromium, lead, cyanide, phenols and fluoride.

The leach tests underpredicted by factors as high as 26 (EP procedure for fluoride) and overpredicted by factors as high as 7.5 (EP procedure for copper) at the 50th percentile levels. The 50th percentile level is that concentration below which 50% of a sample is found.

Organic Parameter Leaching[7]

The objectives of this portion of Phase C were to determine whether organic materials are leached from ferrous foundry waste and whether such materials appear at elevated concentrations in the groundwater immediately downgradient from the landfills.

The original concept of the research was to carry out leaching procedures in the laboratory to determine what organic might be leached from the waste in the field. Subsequently, a field study of various landfills would be tested, using upgradient and downgradient groundwater wells to determine if those organics leached in the laboratory were found in the groundwater at those landfills.

Because of the lack of a leaching procedure which EPA would accept in interpreting laboratory results, the order of the study was reversed with the field study performed first.

Only the general concept and conclusions of the Phase C organics work will be presented here for completeness. A more detailed paper appeared in the July 1989 issue of *modern casting*.

In the field work, groundwater quality was measured at four ferrous foundry waste landfills in Wisconsin. The landfills contained only foundry wastes, and at three of the four sites there was enough background information from previous investigations to determine groundwater flow patterns for well placement. Therefore, the correct placement of wells to intercept any possible leachate

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Flow directions for the fourth site were estimated from a U.S. Geological and Natural History Survey for the geology and water resources of the county containing the landfill.

Whenever possible, three downgradient wells were placed at the waste boundary of each site, adjacent to the oldest portion of the site. An upgradient well was placed at each site far enough from the waste to ensure an accurate representation of background water quality. Well depth monitors were set at both the top few feet of groundwater and at a lower depth, determined, when possible, from vertical gradients established from past data.

Care was taken during well construction and groundwater sampling and analysis to use approved procedures. The wells were constructed of stainless steel; multiple bailings were used to purge each well prior to sampling; proper sample containers and sampling methods were used; and very strict analytical procedures were followed so that volatile organics would not be lost.

Analysis consisted of multiple gas chromatograph-mass spectrometer scans on different sample extracts, followed by gas chromatography confirmation of any compounds observed.

This study concluded that none of the four ferrous foundry landfills generated groundwater samples with detectable levels near the waste boundary of any of the 45,000 organic compounds available in the Wisconsin State Laboratory of Hygiene GC-MS scan library. Trace concentrations of certain organics did appear inconsistently but at levels below the official detection limits for the state laboratory equipment.

The laboratory portion of the work used the proposed TCLP procedure with the zero head extactor (ZHE) that EPA developed for volatile organic parameter leaching. Samples representing nine commonly used binder systems were provided to the university directly by AFS from various foundries.

Each foundry was requested to provide samples reflecting only the desired binder system. If a foundry used more than one binder system, it was included in the study unless wastes from the binder system were completely segregated through different process lines at the foundry.

The results indicated that although a wide variety of organic compounds was detected, most were present at low concentrations. The core oil and phenolic urethane binder system leached the largest number of compounds at the highest concentrations. None of the samples leached organic compounds at or higher than the proposed regulatory levels using the TCLP. Benzene and tetrachloroethene concentrations were slightly above drinking water standards in three leachates.

Highway Construction

A project under way points to possible future waste management strategies for the foundry industry. As indicated, significant amounts of foundry wastes have little potential to contaminate groundwater.

The first objective of this project is to leach test specific wastes thought to have low leaching potential from three ferrous foundries. Parallel leach tests are to be performed using natural soils from several Wisconsin locations.

Second, if the wastes exhibit low leaching potential, they are to be used in test sections to be later incorporated into highway overpass embankments, using appropriate monitoring to evaluate any impact on groundwater quality.

This work is being performed through the cooperative efforts of the Wisconsin Department of Natural Resources, Wisconsin Department of Transportation, the University of Wisconsin and the three foundries that were selected based on their proximity to highway projects and interest in participating in the study.

Results to date indicate that system sand and some core butt materials from the three foundries are of low leaching potential. Laboratory leaching results indicate that most parameter concentrations were below drinking water standards. On average, only iron, manganese and TDS exceeded drinking water standards.

Natural soils leached for comparison with the foundry wastes released comparable and sometimes higher levels of substances. Samples were collected from each foundry over a year to check on waste leaching characteristic variability prior to test area construction. DOT results indicate that the wastes can meet highway construction specifications for physical parameters.

Test piles have been built at two highway construction sites using wastes from two foundries. The third site was not available to the project, so wastes from the third foundry were only tested in the laboratory.

Each site has two piles, one consisting of the selected foundry wastes and the other of natural soils from the area as would normally be used in a highway project. Each pile has three depths, 5, 10 and 15 feet, with each depth underlain by a 10 ft × 10 ft plastic leachate collection membrane. Monitoring includes leachate quality and quantity from each depth and each waste, as well as upgradient and downgradient groundwater quality for each pile.

Only a few data points exist to date and are inadequate to reach any conclusions. Monitoring continued through most of 1989, with decisions on further monitoring to come.

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This work has been made possible through the long-term commitment and guidance of AFS, and the hard work and dedication of many students involved over the project's 17 years.

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