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PUBLIC MEETING ON WASTE LEACHING  
Session III - Leaching Science**

**Inorganic Leaching Science - Dr. William Batchelor**

Dr. William Batchelor, of Texas A&M University, spoke about the state of inorganic leaching science. A copy of Dr. Batchelor's presentation materials is available through the following link: [batchel.pdf](#). He began his presentation by noting that the majority of his research has focused on the leaching of wastes that have been treated by conventional solidification and stabilization techniques. Thus, they tend to be high pH wastes, but the leaching considerations he described can also be applied to other wastes as well.

Dr. Batchelor described leaching in very general terms, stating that when a solid waste is in contact with a fluid, some contaminants will leach from the solid to the fluid. One can look at the process as a continuous one, measuring the concentration of the contaminant in the fluid and the flow rate of the fluid. Alternatively, one can consider a batch process and measure the volume of fluid instead of the flow. Both approaches have uses. Dr. Batchelor noted that the concentration of the contaminants in the leachant becomes a source term for risk assessment models.

The two fundamental issues outlined by Dr. Batchelor are equilibrium and kinetics. When the flow of fluid through the waste is low, there is time for many of the contaminants in the waste to reach an equilibrium with the fluid, and the concentration of a contaminant in the leachant reflects its solubility at equilibrium. Conversely, when the fluid flow is high, the concentration of the contaminants in the leachant is controlled by the rate at which they can dissolve or otherwise be transformed. Dr. Batchelor noted that there are often situations between these two extremes, in which the concentration of a contaminant is a function of both equilibrium process and kinetics. He pointed out that one can design a leaching test to gather information on the equilibrium aspects of the process, the kinetic aspects, or both.

Dr. Batchelor repeated a theme common to many of the presentations at the meeting, that pH controls the leaching on many inorganic contaminants, as well as affecting the speciation of many metals. He showed several graphs of metal concentrations as a function of the pH of the leachant. He noted that for some metal hydroxides, there are maxima in the concentration plots at both high *and* low pH values, with a minimum in the middle of the pH range. This behavior is due to the amphoteric nature of some metal hydroxides, and it can be predicted from first principles.

Dr. Batchelor stated that the sorption of contaminants is controlled to some degree by pH as well, since cations and anions will compete with hydrogen ions and hydroxide ions for sorption sites. He noted that oxidation and reduction reactions are affected by pH as well, and are important in governing the speciation of metals such as arsenic and chromium. The formation of complexes between metals and organic compounds are often controlled by pH as well.

Dr. Batchelor described how the pH of the leachant is determined by the acid neutralizing capacity and the base neutralizing capacity of the waste itself (an important consideration for waste stabilized with alkaline materials such as lime). The pH of the leaching fluid plays a major role in establishing the pH of the leachant, as does the liquid-to-solid ratio. He showed several plots of the solubility of materials leached from a municipal solid waste incinerator ash.

He noted that other factors can play a role, including the presence or absence of surfaces in the waste (e.g., particle size considerations), the presence or absence of ligands (e.g., citrate) within the waste and the leaching fluid, the Eh or redox potential, and the presence of other metals (e.g.  $\text{PbCrO}_4$ ).

Dr. Batchelor described the applications of leaching tests for different purposes. For example, the TCLP is what Dr. Batchelor terms a microcosm test. The test developer envisioned a scenario, co-disposal in the case of the TCLP, and designed a test to simulate that scenario. The results of the test are used to predict which wastes pose an unacceptable risk in that scenario.

In contrast, one can also design a leaching test to generate fundamental data about the leaching processes themselves. Such data can include information on the equilibrium processes, the kinetics of the leaching, or both.

Dr. Batchelor said that the important question is "What do you expect to use the test for?" He noted that the two most common answers are to characterize hazardous wastes, and to assess the risk posed by a waste as it interacts with the environment.

In designing an equilibrium test, Dr. Batchelor indicated that one has to decide what leaching fluid to use. Some common choices include:

1. distilled/deionized water
2. fluids that simulate specific conditions (e.g. TCLP, SPLP)
3. a series of acid/base solutions

One then needs to use small particles and long leaching times to achieve equilibrium conditions. In an equilibrium test, a low L/S is needed to avoid dilution of the contaminants with the leaching fluid itself. The L/S ratio is important in cases where the contaminant concentration is limited by its solubility. It is also important when sorption plays a major role, since larger volumes of leaching fluid will affect the desorption of the contaminants by dilution as well. Dr. Batchelor pointed out that if a high L/S ratio is used, then one can look at how much material can be released, in what is essentially an infinite source scenario, as opposed to how much is released in an equilibrium setting.

A third alternative is to look at the acid or base neutralizing capacity of the waste itself. Often, the acid or base neutralizing capacity controls the pH of the leachant, and the concentrations of the contaminants can be predicted from the leachant pH.

The other approach to designing a leaching test is to consider the kinetics as the controlling factor. Dr. Batchelor noted that kinetics is the study of rate processes. The rates of the various processes that occur in the leaching scenario will affect the leachant concentration. The processes include chemical reactions (speciation) and mass transfer (internal/external). This includes the reactions rates of the contaminants, the dissolution rates, and the rate of diffusion of the dissolved contaminants within the leaching fluid and between the leachant and the surrounding environment.

Dr. Batchelor pointed out that the acids and bases within the waste also leach. In many cases, those acids and bases are more soluble than the other contaminants. As a result, they leach into the fluid, changing its pH, in turn affecting the leaching of the other contaminants. The result can be viewed as a series of "fronts" of leachant that pass through the waste and leach contaminants.

Dr. Batchelor noted that the two most common types of kinetic applications are continuous flow tests and semi-continuous (leachant replenishment). In designing a kinetic leaching test, one seeks to determine the observed diffusivity of the contaminants in the leaching test. The variables that can be manipulated in designing the test include  $Q$  (the flow rate), the  $L/S$  ratio, and the length of the test. One can also use different contaminant concentrations, particularly a low concentration for an "infinite bath" scenario (high  $Q$  or high  $L/S$ , short time), or a high concentration for a low  $Q$  or low  $L/S$ , long time, scenario.

Such kinetic leaching tests may run for several months. During the test, one measures the fraction of the material that has leached. In general, the fraction leached is proportional to the square root of the leaching time. From these data, one can calculate the diffusivity or the leaching index for the material. For every contaminant, there is a different balance of  $Q$ ,  $L/S$ , and leaching time.

Dr. Batchelor described experiments that he has run using an anion exchange resin that removes the metals from the leachant before it is cycled back through the waste. This allows him to use a lower  $L/S$  ratio to simulate an infinite bath scenario in the laboratory.

Dr. Batchelor summarized his presentation by noting that one needs to consider both equilibrium effects and kinetics. He stressed the importance of pH and noted that the concentration of the contaminant in the leachant links the test results to the field situation. He pointed out that tests designed to measure the leachant concentration include those with equilibrium control - equilibrium test for the concentration of the contaminant at equilibrium with the leaching fluid, and those with kinetic control, designed to examine the leachable concentration (availability) and the observed diffusivity, either through measurement or simulation.

At the close end of his presentation, Dr. Batchelor responded to questions and comments. Paul Bishop, of the University of Cincinnati, asked what Dr. Batchelor suggested was the best pH at which to run leaching tests. Dr. Batchelor replied that there is not a single pH that is best for all leaching tests, or all wastes.

Trish Erickson, of OSW, asked how Dr. Batchelor would approach the leaching of a waste that was very likely to undergo reactions, such as the redox reactions that will occur in a waste containing mercury sulfide. Dr. Batchelor replied that the problem with all leaching tests is that you are measuring the characteristics of the waste at the time that the test is begun and not what will happen months or years down the line. He suggested that it may be possible to simulate the conditions that are likely to occur as the waste interacts with the landfill and then perform tests under those conditions. He noted that the same problem occurs when trying to describe the physical characteristics of the waste over a long time frame.

Dave Hassett, of the University of North Dakota, noted that when dealing with alkaline waste, if one runs the test too fast, one will get different results, primarily as a result of the kinetic effects. Dr. Batchelor replied that most of the common leaching tests are designed as a combination of an equilibrium test and a kinetic test. Thus, if one seeks to identify the kinetic effects, one has to design the test accordingly.