Modeling of Reactive Chemical Transport of Leachates from a Utility Fly-Ash Disposal Site

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Abstract

Fly ash from fossil–fuel power plants is commonly slurried and pumped to disposal sites. The utility industry is interested in finding out whether any hazardous constituents might leach from the accumulated fly ash and contaminate ground and surface waters. To evaluate the significance of this problem, a representative site was selected for modeling. FASTCHEM, a computer code developed for the Electric Power Research Institute, was utilized for the simulation of the transport and fate of the fly–ash leachate. The chemical evolution of the leachate was modeled as it migrated along streamtubes defined by the flow model. The modeling predicts that most of the leachate seeps through the dam confining the ash pond. With the exception of ferrous, manganous, sulfate and small amounts of nickel ions, all other dissolved constituents are predicted to discharge at environmentally acceptable concentrations.

Introduction

Coal burning power plants produce large quantities of fly ash. This fly ash is usually disposed of in impoundments or landfills adjacent to the power plants, where it may leach and release hazardous inorganic constituents to underlying aquifers and to contiguous streams. The impact of the hazardous waste releases on the environment depends on the nature of the fly ash and other wastes from the plants, as well as the site geology and hydrology.

For technical and regulatory reasons, it is advantageous to use

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mathematical simulators to predict the behavior and transport of leachates. The Electric Power Research Institute has sponsored the development of a proprietary simulator, FASTCHEM. The code permits two—dimensional modeling of steady—state groundwater flow through the saturated and the vadose zones with simultaneous chemical reactions between groundwater and the soil. Precipitation, dissolution, ion exchange, and adsorption of dissolved chemical species may be modeled.

FASTCHEM's modular structure and overall organization are shown in figure 1. EFLOW implements the Galerkin finite—element method on two—dimensional domains using rectangular and/or triangular elements. The flow in a vertical cross—section may be saturated or unsaturated. EFLOW can accomodate specified head and flux boundary conditions, recharge, potential infiltration/evaporation, seepage, and transpiration. The ETUBE module utilizes the hydraulic head computed by EFLOW to construct streamtubes along pathlines. Streamtubes consist of series of equal—volume "bins" used for geochemical equilibrium calculations in EICM. Chemical processes are incorporated through ECHEM and EICM. ECHEM is used to set up the chemical conditions in the soils and the chemical composition of bounding influxes from groundwater, atmospheric precipitation, and leaching fly ash. EICM simulates reactive chemical transport of aqueous solutions through the sequence of bins in the streamtube, keeping track over time of the chemical components in the aqueous phase and monitored species.
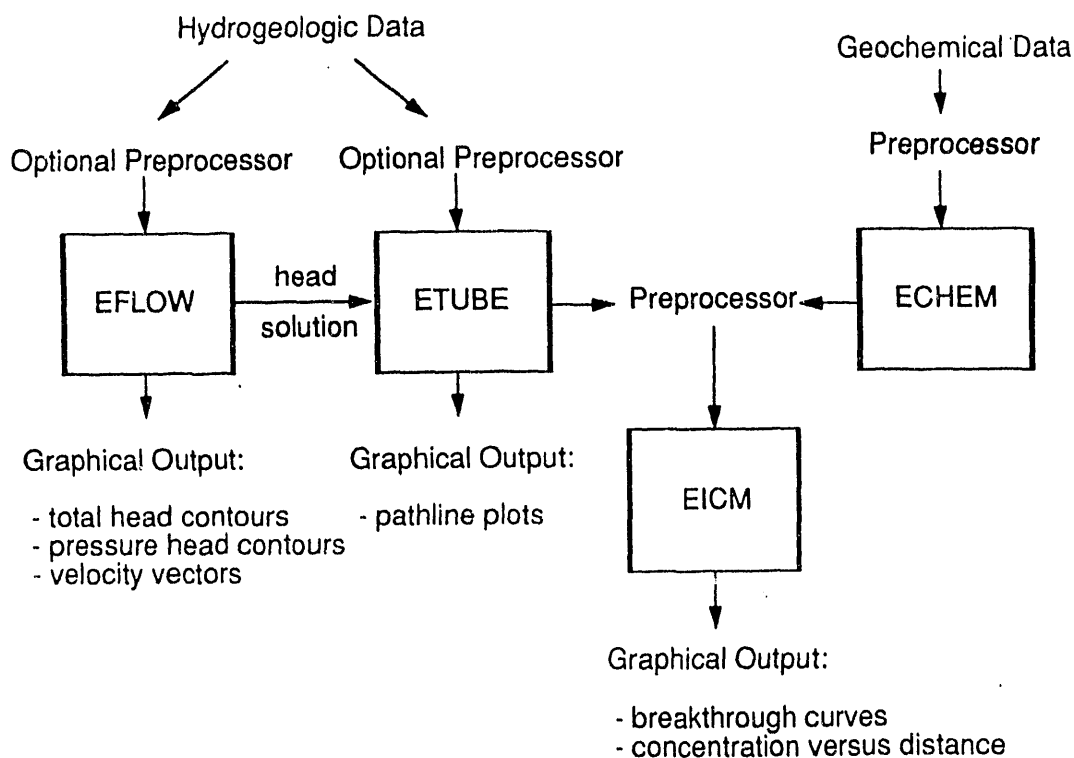

Figure 1. FASTCHEM's modular structure.

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This work summarizes the results of a study on a representative site, located in the Southeastern United States. The fly–ash pond at this site is constructed adjacent to an alluvium–filled stream channel, and rests partly on this alluvium and on saprolite. Figure 2 depicts a vertical cross–section of the pond and the underlying formations approximately along the direction of flow.
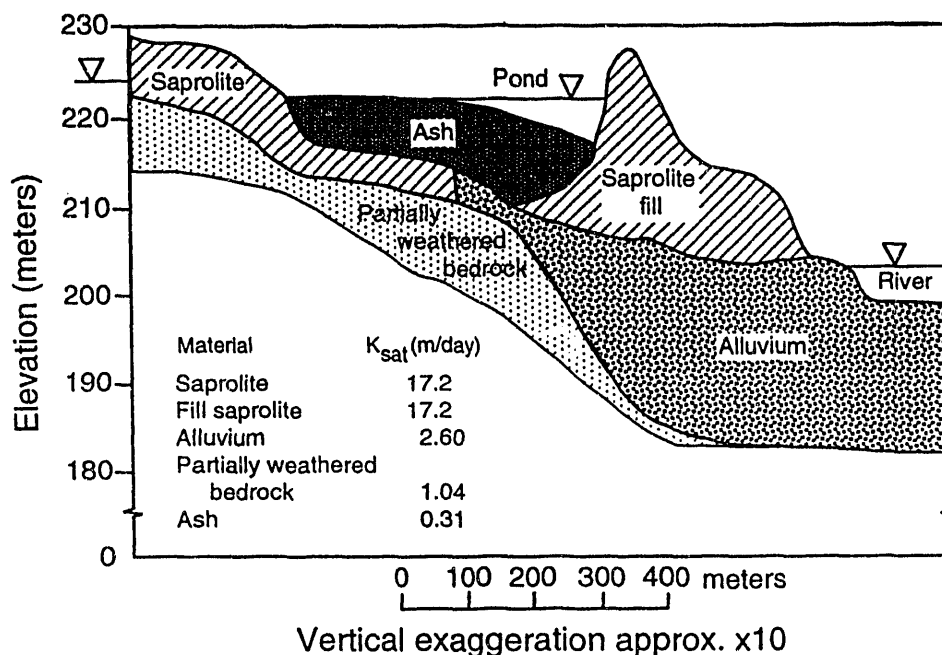

Material	K_{sat} (m/day)
Saprolite	17.2
Fill saprolite	17.2
Alluvium	2.60
Partially weathered bedrock	1.04
Ash	0.31

Vertical exaggeration approx. x10

Figure 2. Geological cross–section.

Overview of Geohydrology

The fly–ash pond has been in operation for about 16 years and has been the subject of field studies and monitoring. We have been furnished with limited site data determined from these field studies. *In–situ* materials are saprolite, alluvium, and a partially weathered bedrock, all underlain by an unweathered bedrock. A 5 to 10 meter thick ash layer has been formed in the pond. The hydraulic conductivities used in modeling are shown in figure 2; the underlying bedrock is treated as impermeable.

The subsurface flow in this vertical cross–section was modeled using prescribed–head boundary conditions at the upgradient and downdradient (river) boundaries, an impermeable base, and prescribed head in the pond. Surface infiltration and evaporation were deemed negligible outside of the leachate pond. Potential seepage surfaces were specified along both saprolite faces and the observed seepage surfaces were successfully modeled. About 96 percent of the outflow

occurs at seepage surfaces at the downgradient face of the saprolite dam. The finite—element grid consists of 947 triangular elements and 547 nodes. This relatively dense discretization is needed to ensure smooth pathline tracking in ETUBE.

Representative pathlines and travel times, obtained through ETUBE, are shown in figure 3. Pathlines 1 and 2 are forced to the surface by the hydraulic barrier created by the leachate pond. Pathline 3 exits the domain at the river. Pathlines 4 and 5 flow through the saprolite dam exiting at the seepage surface.
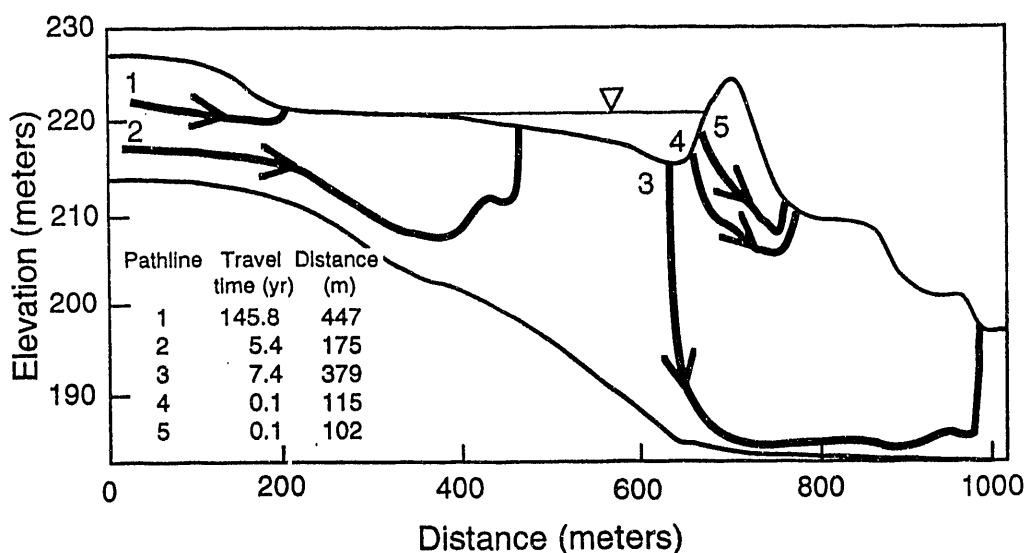

Figure 3. Representative pathlines.

Geochemistry

Limited information is available regarding the mineralogical composition of the partially weathered bedrock, saprolite, and alluvium at the site. Soil samples and the accumulating ash were examined for clay content, cation exchange capacity and species on clay exchange sites, and the hydroxylamine hydrochloride extractable iron content. Groundwater samples from all three soil horizons and the ash pore water had been recovered and their chemical composition determined. These data were employed in ECHEM to set up realistic initial geochemical conditions for EICM.

For illustrative purposes, we present a simulation of reactive chemical transport processes along a representative streamtube. This streamtube begins at the base of the ash (near streamtube 3 in figure

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3), passes through saprolite and alluvium, and discharges in the adjacent river. The streamtube has a total length of about 360 meters. The simulation was conducted over a period of six years. EICM plots indicate that a modified ash pore water breaks through the end of the selected steamtube after about four years.

The changing concentrations of some of the aqueous chemical components as they emerge from the streamtube over time are illustrated in figure 4. The components can be subdivided into two types: conservative and nonconservative. Conservative components are those whose concentrations are modified only by dispersion. In this particular simulation, the conservative components are Mn^{++}, Fe^{++}, Ni^{++}, Cu^{++}, Cl^-, and CO_3^-. The remaining components are all affected to some extent by adsorption, ion exchange and precipitation/dissolution reactions. These include H^+, Na^+, K^+, Mg^{++}, Ca^{++}, Zn^{++}, Fe^{++}, and SO_4^-. H^+, Ca^{++}, Al^{+++}, and $Si(OH)_4$ also participate in soil mineral dissolution reactions. Potassium jarosite is the only mineral that has the potential to form from leachate interactions with the soil.

The principal chemical interactions predicted by EICM involve ion exchange on clays and adsorption on hydrated ferric oxide (HFO). The distribution of species on clays is illustrated in figure 5. The dominant species throughout the streamtube are CaX_2, and MgX_2. As the pore water advances through the soil, Ca^{++}, K^+, Zn^{++}, and H^+ displace Mg^{++} and Na^+. Only a small amount of Zn^{++} is adsorbed, the total Zn^{++} content in solution remaining close to that in the leachate. Chemical reactions on HFO—sites are dominated by replacement of HFO—H by HFO—$H_2SO_4^-$ upon contact with the migrating acidic leachate.

Conclusion

The FASTCHEM simulations predict that about ninety six percent of the discharge from the fly ash impoundment occurs through the saprolite dam and adjacent pond bottom to emerge as seepage at the foot of the dam face. Only four percent of the discharge passes through the accumulated ash into groundwater. Fe^{++}, Mn^{++}, and small concentrations of Ni^{++} will leach from the accumulating fly ash and discharge to the groundwater and adjacent river.

Acknowledgement

Appendix I. — References

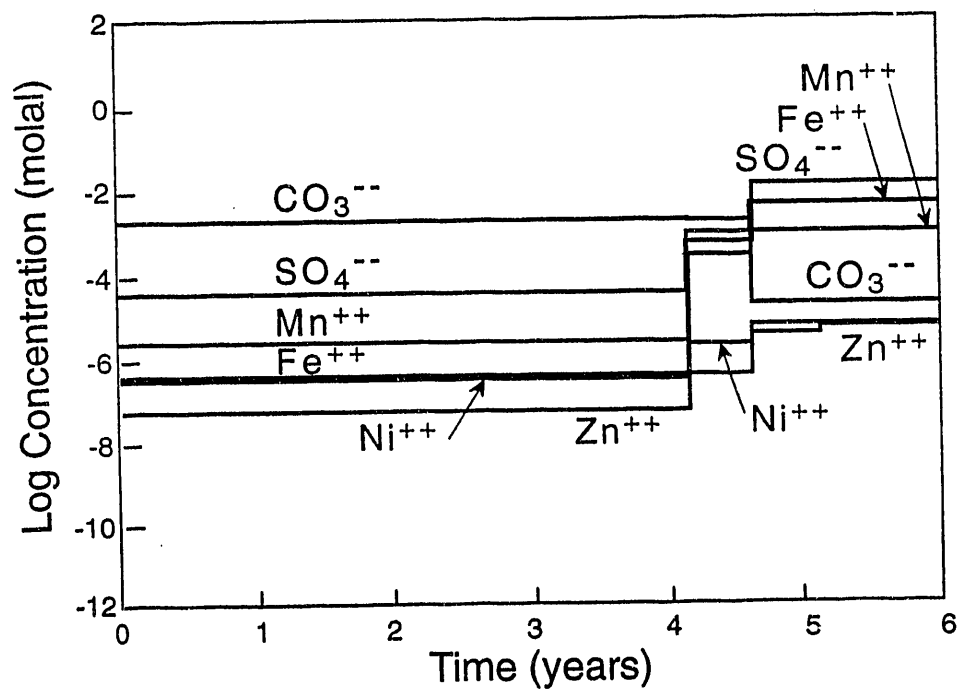EPRI, FASTCHEM Package, Volumes 1—6, EA—8570—CCM.

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Figure 4. Concentrations of some aqueous chemical components as a function of time.
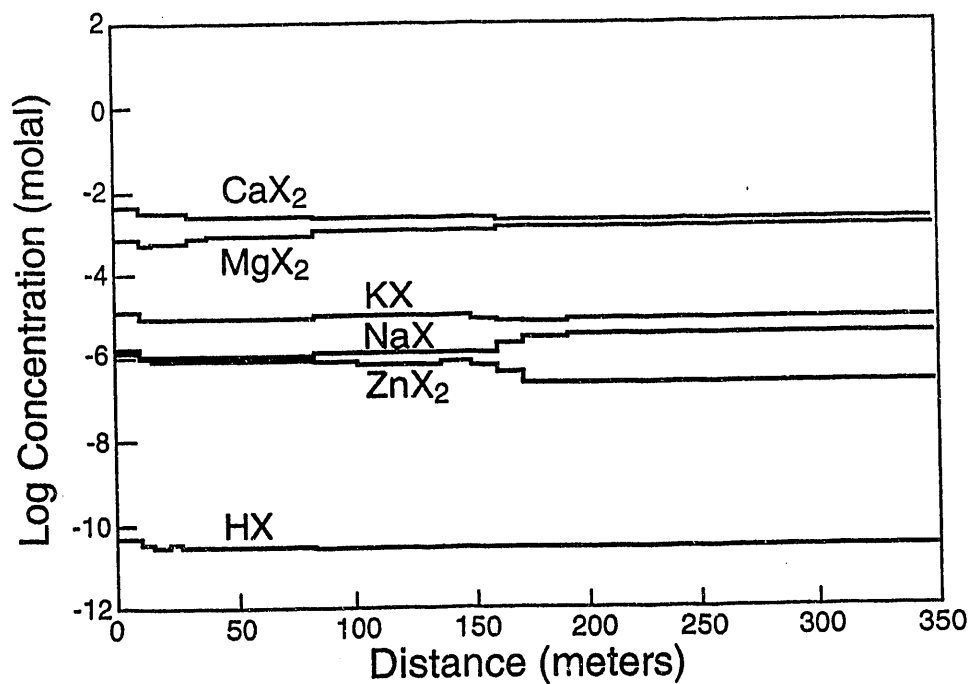

Figure 5. Distribution of species ion—exchanged on clays, two years after the ash leachate migrated into the soil.

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