HEAT REMOVAL OPTIONS AND TEMPERATURE PREDICTIONS FOR A VAULT OF GROUTED WASTE

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ABSTRACT

The U.S. Department of Energy's Grout Disposal Program immobilizes low-level radioactive wastes that are stored in double-shell tanks on the Hanford Site. The wastes are mixed with cementitious materials to form a grout. The resulting slurry is then pumped into large underground vaults. Westinghouse Hanford Company developed a method to predict the transient temperature response of these vaults to the heat of hydration of the grout. This method was also used to investigate several options for removing some of the energy generated by the hydration reaction. The results of those analyses are presented here.

INTRODUCTION

Approximately 75,000 m^3 of waste (liquids, sludges, and slurries) are currently stored in double-shell tanks on the Hanford Site. The low-level portion of the waste stored in double-shell tanks and the low-level waste fraction resulting from pretreatment operations are to be incorporated into a grout matrix at the new Grout Treatment Facility. The grouted wastes will then be disposed of in large (5,300 m^3) near-surface vaults on the Hanford Site. The Grout Treatment Facility became operational in 1988 and has recently completed the processing of the first 3,800 m^3 of nonhazardous low-level waste. Disposal of the hazardous (mixed) wastes stored in double-shell tanks is scheduled to begin in fiscal year 1991.

A methodology has been developed to predict the transient temperature response of the first vault to be filled with Hanford Site double-shell tank grouted waste. If the vault is continuously filled at the normal grout production rate, then the heat of hydration of the originally proposed grout mix was large enough to raise the temperature of the mixture above the proposed temperature limit of 90°C. Several heat management options were investigated to reduce the peak temperature to acceptable values, including active and passive cooling systems and reduced grout-pouring rates. In addition, a revised grout formulation designed to reduce the heat of hydration is currently under development.

DISCUSSION OF METHODS

The method for modeling the thermal response of these vaults to grout pouring is dependent on a characterization of the heat generated by the hydration reaction of the grout mixture. Because of the radioactivity level of the waste, a waste simulant is used to obtain data about the heat of hydration of the mixture from laboratory-scale calorimetry experiments. Two types of calorimetry tests were performed to characterize the heat of hydration of the grout. The data indicated that the temperature rise was acceptable. When a larger scale (insulated but not adiabatic) instrumented pilot pour of the grout simulant was made, the resulting grout temperatures exceeded 100°C. Based on the available calorimetry data, the volumetric hydration heat rate was characterized as a function of two variables: current temperature and the total heat generated since the reaction started. The basis for the development of functional form came from the adiabatic data supplied by Pacific Northwest Laboratory. The Oak Ridge National Laboratory isothermal calorimetry data was used as a verification of the total heat produced and as a qualitative verification of the correct functional form. Figure 1 shows representative temperature rise data from these adiabatic calorimetry tests for nominal starting temperatures of 25, 35, and 45°C and the corresponding heat-generation data. Figure 2 shows the heat-generation rate as a function of current temperature and total heat generated. This function was synthesized from the data in Fig. 1 by eliminating time as an independent variable, and was used to drive the resulting thermal models.

The analyses reported herein were done using the ANSYS* finite-element code. The volumetric heat-generation rate for a specific element for each time step of the transient was computed based on two independent variables, current element temperature and the total heat generated by the element up to this point in the transient. The function used for this computation is shown in Fig. 2. Continuous pouring of grout over the time of the transient was simulated by changing the thermal conductivity of successive layers of elements inside the vault as the pouring scenario progressed. Concurrently, the thermal loads on the same layers of elements were redefined to be volumetric heat-generation rates consistent with the function shown in Fig. 2. Heat transfer links were also included in the model to simulate radiant heat transfer and convective heat transfer from the surface of the grout. The inlet temperature of the grout mixture was set to 45°C.

VAULT DESIGN

The inside dimensions of the proposed vault are about 125 x 50 ft, with a depth of 34 ft. The depth of radioactive

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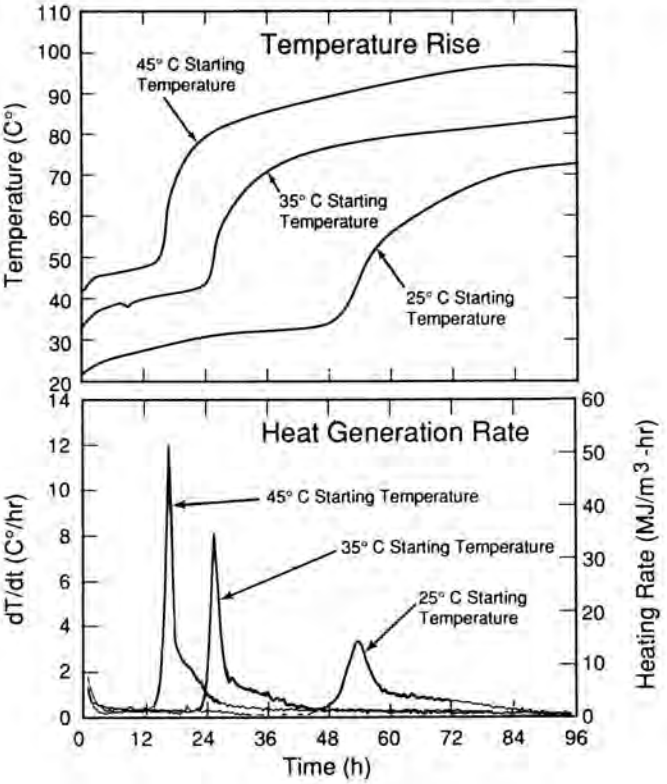


Fig. 1. Representative Adiabatic Calorimetry Data.

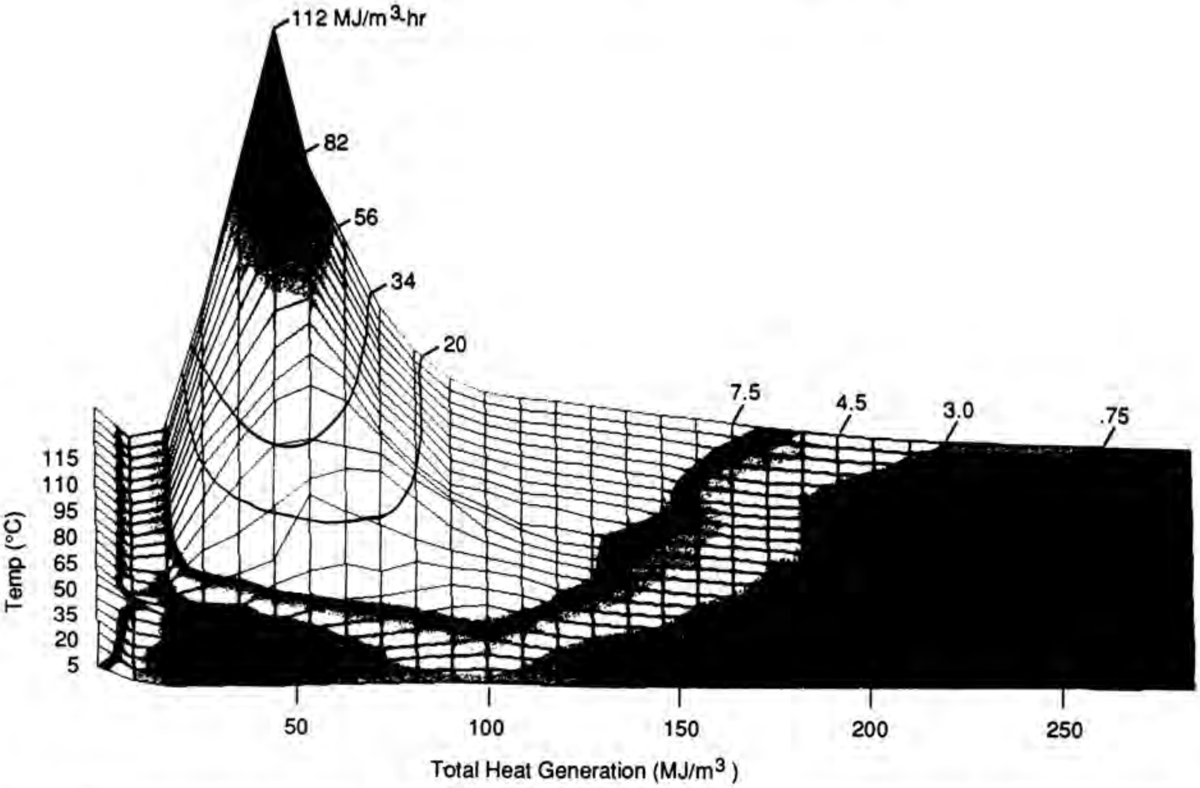


Fig. 2. Functional Relationship for Heat Generation Rate Versus Temperature and Total Heat Generation.

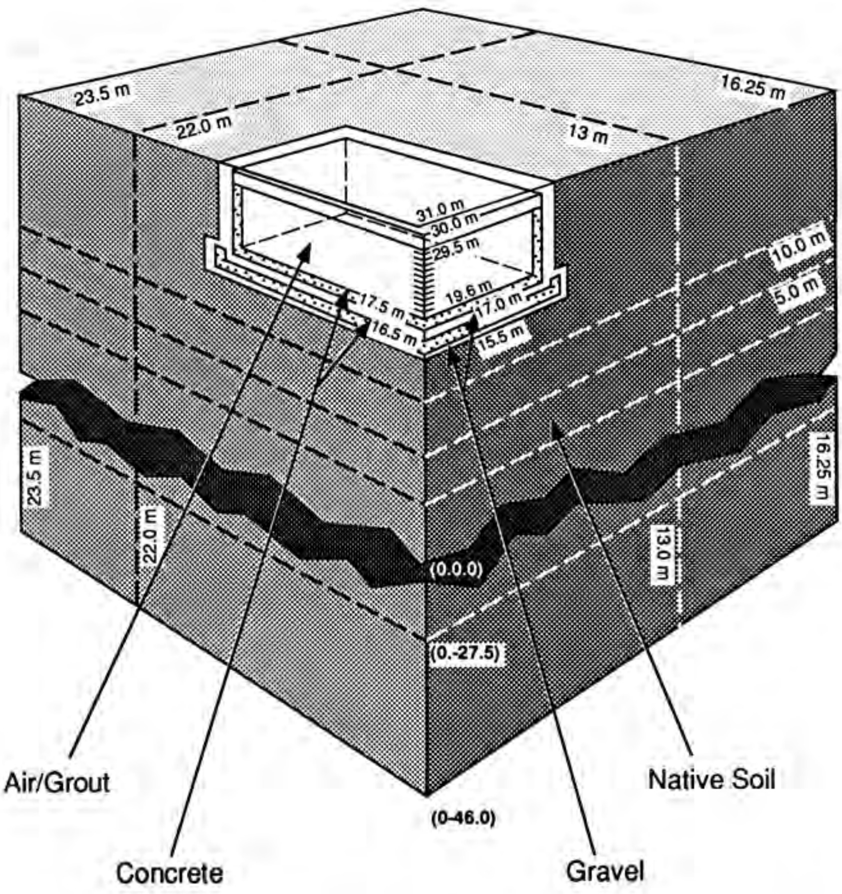


Fig. 3. Section of Vault and Surroundings Included in Finite Element Model.

grout will be 30 ft when the vault is full. A three-dimensional, finite-element model of a quarter section of the vault and surrounding soil was constructed. Figure 3 shows the segment of the vault and surroundings that was included in the model. The proposed vault design includes a ventilation system to maintain a subatmospheric pressure inside the vault that is capable of removing some heat, mostly in the form of latent heat from the grout surface. This feature of the vault design was modeled as a constant heat flux from the surface of the grout. When the model was run through the proposed filling scenario, it was discovered that the grout in the center of the vault was subjected to conditions that were nearly adiabatic, mainly because of the low thermal conductivity of the grout. This resulted in unacceptable peak grout temperatures.

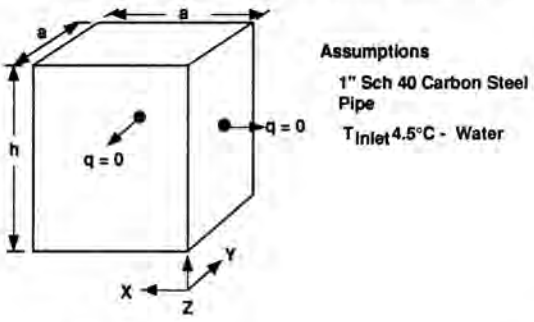
RESULTS

There is a limit to the possible rate of heat removal from the grout surface. This limit is imposed by the poor thermal conductivity of the grout. Simulation of a depressed free-surface temperature in conjunction with a pouring scenario at the desired rate showed that the actual heat generation took place at some depth in the grout mass because of the time lag between mixing of the grout and the peak of the hydration reaction, and that the poor thermal conductivity of the grout imposes a practical limit on the rate of heat removal from the free surface of the grout mass. This fact provides the rationale for investigation of an active cooling system, because an active system embedded in the grout would not be governed by this restriction. Methods to enhance the conductivity of the grout were also investigated.

Several methods to depress the peak grout temperature were investigated, including active cooling pipes in the grout. Figure 4 shows the unit cells used to conduct a study of the concept of an active cooling system and a study of conductivity enhancement of the mixture by inclusion of a matrix of reinforcing steel in the grout.

Because the only effective heat-removal method near the center of the grout is either from the free surface of the grout or internal to the grout (i.e., active cooling coils), one-dimensional models were used to perform these assessments. The boundary conditions and assumptions used for

Unit cell representation for active cooling system analysis



Unit cell representation for enhanced conduction analysis

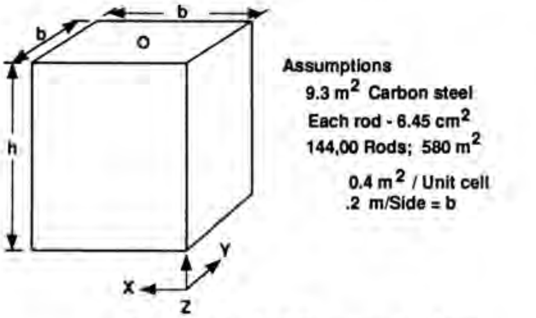


Fig. 4. Unit Cell Representations.

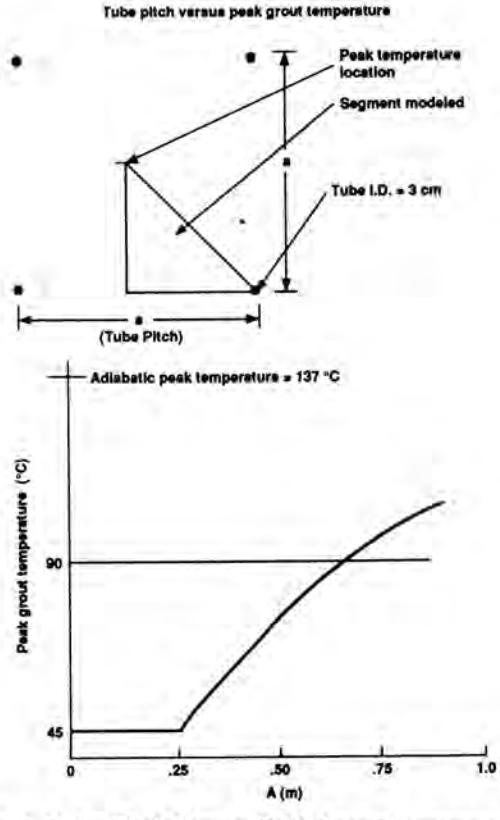


Fig. 5. Tube Pitch Versus Peak Grout Temperature.

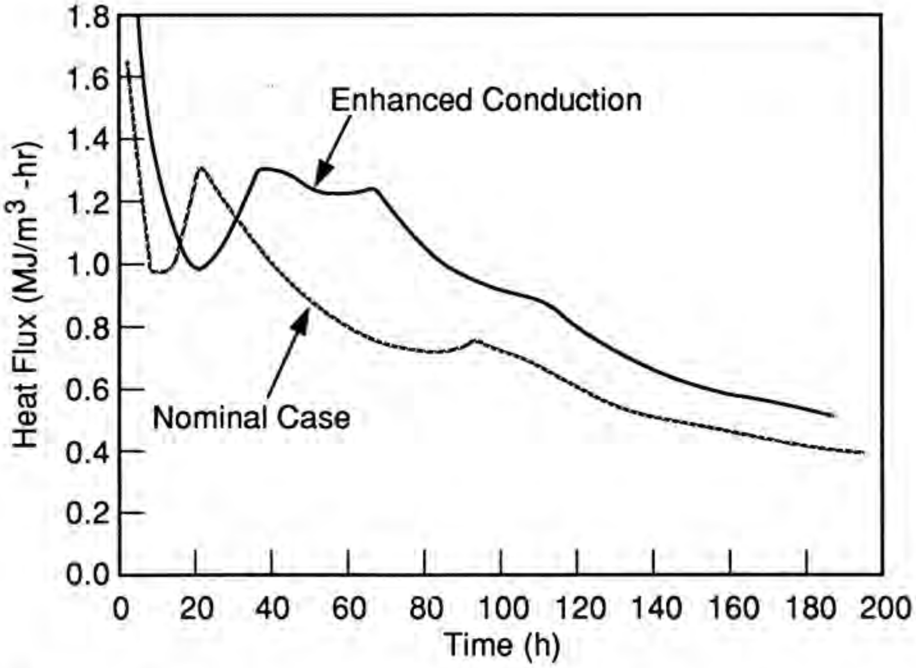


Fig. 6. Comparison of Surface Heat Flux Between Nominal Case and Enhanced Conduction Case.

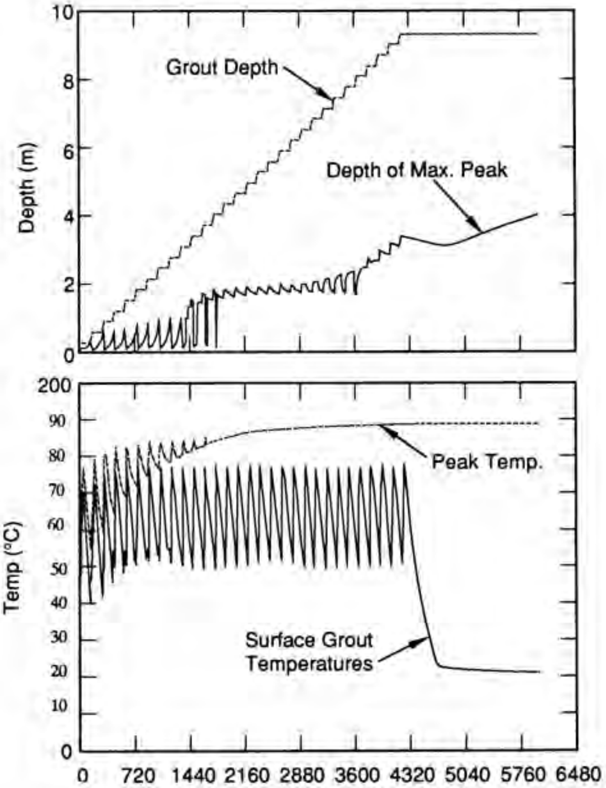


Fig. 7. Depth of Grout and Grout Temperatures for Stages Pour Scenario.

these cases are representative of what would be expected near the center of a full-scale vault.

A diagram of the model used to conduct the active cooling studies and the results in terms of peak grout temperature versus pipe pitch are shown in Fig. 5. Up to a pitch of about 0.25 m, the thermal conductivity of the grout is adequate to allow removal of all the heat produced by the hydration reaction, so the grout never exceeds the initial temperature. For tube pitches in the range of 0.25 to 0.69 m, the results were acceptable. At a tube pitch of about 0.69 m, the grout is no longer able to conduct the heat to the cooling pipe at a rate adequate to depress the peak temperature below the proposed limit of 90°C. This pitch requires about 11 km of cooling pipe for each vault.

Figure 6 shows the gain in surface heat flux that can be effected by the addition of large amounts of reinforcing steel in the grout (to increase the effective conductivity and provide some added heat capacity). This approach results in about a 20 percent improvement in surface heat flux and could reduce the vault-filling time by 30 to 40%. Inclusion of the conduction-enhancing steel in the amount shown in Fig. 4 requires about 625 tons of steel for each vault.

A one-dimensional model was constructed to do scoping studies for staged pour scenarios. The results of these simulations showed that the temperature of the grout could be kept below the proposed 90°C limit when grout was poured in small-enough increments. The time required to fill the vault was dependent on the postulated ventilation system heat-removal rate. Figure 7 shows the transient temperature response for the peak and surface grout temperatures at the expected ventilation system heat-removal rate. It also shows the location of the peak temperature in the grout mass as the pouring progresses.

SUMMARY

The use of active cooling systems or attempts to enhance the thermal conductivity of the grout appear to be costly in terms of additional materials and work required. A solution to the problem of heat removal may be to reduce the filling rate of the vault to the point that the ventilation system is capable of removing the excess heat resulting from the hydration reaction. While the mixing machinery for the waste and grout is not able to operate at a slow enough rate to do this on a continuous basis, it is possible to fill several vaults on an intermittent basis (e.g., rotate the filling among several vaults) and achieve the same results. It appears that it will take approximately 6 months or roughly 10 times longer to fill a vault than was originally planned. A viable alternative to the heat-removal approaches discussed in this report is the reformulation of the grout mixture, which willreduce the vault filling time and is currently being investigated in the grouted waste facilities.

REFERENCES

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