MASTER

SENSITIVITY OF CALCULATED PORE FLUID PRESSURE TO REPOSITORY FRACTURE GEOMETRY*

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ABSTRACT

Calculations have been made to predict the sensitivity of pore-fluid pressure to the geometry of rock fracture patterns in the near vicinity of nuclear waste buried in a tuff repository. The SHAFT 79 code (for multi-dimensional, two phase flow in porous medium) has been used. The repository considered contains 1.0, 2.1 and 2.5 kW/can, canisters emplaced in welded tuff with a global repository loading of 75 kW/acre. The resulting calculations show that predicted pore fluid pressures vary from 55 bars for a homogeneous, fracture-free rock mass to 5 bars for a well fractured mass. This order of magnitude variation shows the importance of properly modeling fracture patterns in hard rock repository analysis.

INTRODUCTION.

Numerous one-and two-dimensional thermal analyses have been made to assess the consequences of radioactive waste burial in various geologic media.¹ These models provide complete temperature fields for a wide range of materials and heat loadings but are incapable of predicting pore-fluid pressures

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(pore pressure), boiling-front locations, dry out and convective energy transport. The pore pressures obtained in an earlier study for argillite² and for tuff, using the two-phase flow code, SHAFT³, for a saturated homogeneous (fracture-free) repository with perfect backfill, exceed the local lithostatic load by more than 600 bars. Such overpressures could significantly affect the integrity of a repository since typical tensile strength of these rocks are of the order of 10 bars. These pressure calculations may be unrealistic in that they do not consider volatile release by means of the fractures inherent in welded tuff.

This paper extends this previous study to show the importance of pressure-relieving fractures in the vicinity of a single waste canister at times prior to backfilling the drift. Material properties for the tuff considered in this paper are: conductivity = $3 \text{ W/m}^\circ\text{C}$, density = 2280 kg/m^3 , specific heat = $1597 \text{ J/kg } ^\circ\text{C}$, matrix permeability(k) = 4×10^{-7} darcy, fracture permeability (k_f) = 1 darcy, porosity(ϕ) = 23%. Also assumed are global repository loading = 75 kW/acre , extraction ratio = 20%, and canister loading (Q) = 1.0, 2.1 and 2.5 kW/can . The permeability value is representative of a minimum value measured on the matrix of simple devitrified welded tuff.

ANALYSIS

The geometric nodalization used is based on an effective radius or unit cell concept. This approximation transforms the exact three dimensional configuration into an equal mass axisymmetric shape, Fig. 1. The floor of the repository drift is located 710 m below the ground surface. The drift is held at 1 atmosphere to simulate conditions prior to drift backfill. The welded tuff is assumed saturated. Four near field fracture geometries are considered in this study as shown in Figure 1(a)-(d). The geometries of the four cases are: (1) homogeneous material (welded tuff) no fractures, base case, (Figure 1a); (2) a single axisymmetric fracture surrounding the canister (at r = radius of canister (.165 m) plus radius of tuff block) which extends to the floor of the drift, (Figure 1b); (3) two horizontal fractures separated by 0.5 m and two vertical fractures extending to drift floor at $r = r_{\text{canister}}$ and $r = 0.665 \text{ m}$, torus, Figure 1c); and (4) the tuff in vicinity of canister assumed to consist of three dimensional "pie" shaped rock blocks with mean cross sections of 0.5 m surrounded by fractures on all six sides, (Figure 1d). In all cases the fracture width is taken to be 1/100 of the width of the homogeneous tuff block of interest and to have a permeability 10^7 larger than the block permeability. In each case the pore pressure (p^*) of interest (see Figure 1) is the maximum calculated pore pressure in the block of interest. Results were obtained using the two-phase lumped

Fig. 1. Fracture Geometries. (Scales are different in each drawing to emphasize important features)
 (a) Homogeneous Fracture Free Column Extending to Ground Surface (* is point of interest)
 Figures (b), (c) and (d) Refer to Details of the Three Fracture Cases. (b) Single Axisymmetric Fracture Case (c) Multiple Fractures about Torus Shaped Homogeneous Block (d) Three Dimensional Block with Fractures on all Six Sides. (Drift floor considered but not shown)

Fig. 2. Nodalization Used for Single Axisymmetric Case (Geometry 2) shown in Figure 1b.

parameter code SHAFT 79. The nodalization was kept moderately simple and therefore the run times were reasonably short (100 to 200 s). The computational grid for case 1 extends from 30 m below the drift floor to the ground surface and uses 102 elements. Details of the computational grid for case 2 are given in Figure 2. This case is essentially one-dimensional axisymmetric except for the vertical flow through the fracture to the drift which is caused by the expansion of pore water when heated. The nodalization for case 3 is like that shown for case 2 with the addition of horizontal and vertical fracture regions. Case 4 has the third dimension added.

SUMMARY OF RESULTS

An initial parametric study determined the sensitivity of pore pressure to matrix permeability (k). Geometry 2 was used for this study with a canister loading (Q) equal to 1.0 kW/can. Figure 3 shows that for k larger than 10^{-5} darcy, pore-pressure increases due to heating are not significant. For k smaller than 10^{-7} d the peak pore pressure becomes a strong function of permeability and can be significant with regards to structural integrity. Figure 4 shows the effect of block size on calculated peak pore pressures for geometry 2 with $Q = 2.5$ kW. A summary of this type of calculation is given in Figure 5 for $Q = 1, 2.1$ and 2.5 kW/can. It can be seen from Figures 4 and 5 that the calculated peak pressures occurs within one day after canister emplacement and is approximately linear with block size for a given canister output. Figure 6 gives pressure as a function of time for the four geometries, $Q = 2.5$ kW/can. It shows that fluid

Fig. 3. Effect of Tuff Permeability on Fluid Pressure Increase. Geometry 2, $r_b = 0.5$, $Q = 1.0$ kW/can

Fig. 4. Effect of Tuff Block Size on P^* , Geometry 2, $Q=2.5$ kW/can, $k=4 \times 10^{-7}$ darcy.

Fig. 5. Peak Pressure as a Function of Block Size and Canister Output $k = 4 \times 10^{-7}$ darcy Geometry 2.

Fig. 6. Effects of Fracture Geometry on Pressure, $Q = 2.5 \text{ kW/can}$, $k = 4 \times 10^{-7} \text{ darcy}$.

Fig. 7. Canister Cooling Caused by Convection in Fractures, $Q=2.5 \text{ kW/can}$,

pressure is strongly coupled with the geometry of the fractures in the vicinity of the canister and drift. Peak pressures decrease from 55 bars for the homogeneous fracture free geometry to less than 5 bars for the three-dimensional fracture array. Inclusion of general fracture array which connects the drift to regions near the canister greatly reduces the maximum calculated pore pressures. Neglecting the existence of a fracture array could result in calculated peak pressures up to an order of magnitude too large.

The radial temperature distributions for the four geometries are given in Figure 7 for a heat loading of $Q = 2.5 \text{ kW/can}$, and a time of 10 days after emplacement. These curves show that the temperatures at small radii are appreciably lower for geometries 3 and 4. It appears that the additional fractures provide convective pathways sufficient to effect the otherwise conduction dominated temperature distributions. None of these cases contained boiling regions at the time when maximum pressures existed. For $Q = 2.5 \text{ kW/can}$, some two-phase and vapor flow existed at later time (3 days). Figure 8 gives the pressure,

Fig. 8. Temperature and Pressure Near Canister at 10 Days After Burial, $Q = 2.5$ kW/Can.

temperature and volume fraction of vapor for this boiling case. For the purpose of modeling geologic medium properties, it is often assumed in conduction calculations, that boiling occurs at 100°C and 1 atmosphere.⁴ Figure 8 shows that this assumption not applicable for this case, since the boiling front occurs between 140 and 160°C at a mean pressure of 5.5 bars.

This study shows the effects of fracture network on thermo-hydrology in the vicinity of a nuclear-waste canister. The presence of fractures has been shown to have a weak but non-negligible influence on resulting temperature profiles and a strong influence on the resulting pore fluid pressures. The presence of fractures decreases the calculated maximum pressure through two mechanisms. First, the reduced resistance to flow through fractures gives the increased volume of the slightly compressible pore water a path through which to migrate away from the hottest regions, thus directly reducing the pressure. Secondly, the movement of fluid in the fractures provides some convective cooling in the conduction dominated problem. It should be emphasized that the details of fracture geometry do not appear extremely important, so long as fractures extending from the very near region of the canister to the drift floor are included, in which case calculated pore pressures are significantly decreased.

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