MODELLING THE FLOW

GROUNDWATER IN THE VICINITY OF A SALT DOME

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ABSTRACT

Radioactive waste from a repository in a salt dome can be transported to the biosphere by flowing groundwater, after contact of groundwater with the disposed material.

In order to be able to describe the transport of radionuclides by flowing groundwater, the velocity in the vicinity of the salt dome must be calculated. This velocity field will especially be influenced by large gradients in the liquid density. The liquid density will vary from 1200 kg/m^3 close to the salt dome to 1000 kg/m^3 further away.

Results of calculations performed in a two-dimensional vertical model show that the effect of the liquid density on the velocity field is very pronounced.

INTRODUCTION

The rate at which radionuclides, released from a repository in a salt dome will be transported by flowing groundwater to the biosphere, is dependent on a number of physical/chemical processes like advection, diffusion, dispersion, adsorption, etc. The effect of some of these processes will strongly be influenced by the concentration of salt in the groundwater, e.g., the speciation and, hence, the adsorption characteristics of some radionuclides are dependent on the salt concentration. Advection, i.e., the movement of groundwater, is also influenced by the salt concentration, mainly through the effect of the liquid density on the flow field.

In case of groundwater flow in the vicinity of a salt dome, we have to deal with large differences in liquid density. Close to the salt dome, the groundwater will be saturated with salt, resulting in a density of 1200 kg/m^3. Moving away from the salt dome, the liquid density will gradually decrease to 1000 kg/m^3. Hence, the liquid density gradients will be much larger than normally encountered in groundwater flow problems.

Nowadays, it is more or less common practice to use numerical models to predict the transport of solutes by flowing groundwater. Although a number of computer programs is available in this field[1], only few of those are designed to treat situations where the liquid density plays an important role.

To investigate the effect of the liquid density on the flow field in the vicinity of a salt dome, calculations were carried out for a two-dimensional, vertical model. When using an existing model[2,3], numerical problems were encountered. These problems were due to the fact that the liquid density is treated (partly) explicitly, giving rise to instabilities in the transient solution of the equations. This problem can be cured by treating the liquid density fully implicit. Further investigation showed that an accurate definition of the liquid density as a function of the salt concentration is required to obtain a good estimate of the velocity. Small deviations in the liquid density may result in large deviations in the velocity.

EFFECT OF LIQUID DENSITY

To study the effect of the liquid density on the flow field in the vicinity of a salt dome, calculations were carried out for isothermal, single phase flow in a two-dimensional, vertical cross section, taking into account advection, diffusion and dispersion. It should be pointed out that this strongly simplified model does not represent real situation, but merely serves as an example.

Model Characteristics

The geometry and dimensions of the vertical cross section are shown in Fig. 1.

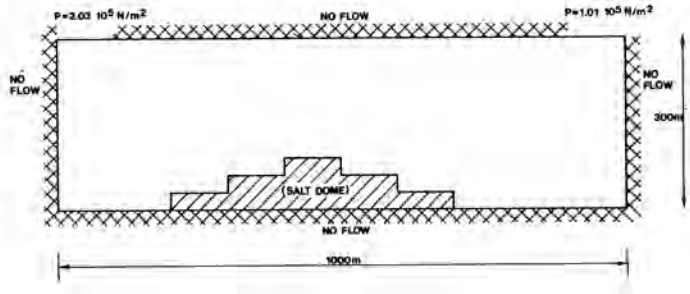

Fig. 1. Model geometry and dimensions.

The model is homogeneous and isotropic. Its characteristics are:

permeability	10^{-12} m^2
porosity	0.25
diffusion coefficient	10^{-9} m^2/s
longitudinal dispersivity	20 m

vertical dispersivity	2 m
liquid viscosity	10^{-3} Ns/m^2

The liquid viscosity is assumed to be constant. The liquid is described as a mixture of fresh water with a density of ρ_f and saturated brine with a density of ρ_b. The composition of the liquid is given by the mass fraction c of brine. Hence, c can vary from 0 to 1. The part of the model indicated as "salt dome" is virtually impermeable.

The pressure boundary conditions are also indicated in Fig. 1. The pressure is maintained at a constant level on two parts of the model boundary, while the rest of the boundary is closed (no flow boundary). Due to this boundary conditions, groundwater flow from top left to top right will occur. The pressure difference is much larger than normally found in practice. The mass fraction of brine in the inflowing water is 0, while the mass fraction brine in the outflowing water is given by the mass fraction in the model. At the boundary of the salt dome, c is maintained at a value of 1 (saturated brine).

Initially, the pressure distribution in the model is hydrostatic, while the mass fraction of brine is 0 everywhere. All simulations were carried out with a finite difference model, using 10 * 10 equally sized grid blocks. Starting from the initial conditions as given above, transient calculations were carried on until a steady state solution was obtained. The time step size was chosen such that the maximum change in the mass fraction brine did not exceed 0.03 per time step. For each simulation, the steady state distribution of the mass fraction of brine and the velocity field, steamlines and residence times were calculated, using linear interpolation for the velocity and a first order correct integration scheme with a very small step size for the streamlines and residence times.

Four different simulations were performed with this model, using the same characteristics and boundary and initial conditions for each simulation but changing the treatment and/or definition of the liquid density. The four simulations are:

1) Flow without density gradients

2) Liquid density is a linear function of the mass fraction brine; density is treated partly explicit

3) Liquid density is a linear function of the mass fraction brine; density is treated fully implicit

4) Liquid density is a quadratic function of the mass fraction brine; density is treated fully implicit.

Constant Liquid Density

The situation for a constant liquid density was simulated with an existing model [2,3] by giving the brine density ρ_b the same value as the fresh water density ρ_f (=1000kg/m^3) and making the liquid density a linear function of the mass fraction brine:

(1)

Figure 2 shows the steady state velocity field calculated for this situation. Velocities are in the order of 0.05 m/d. From this velocity field, streamlines from top left to top right of the model have been determined. These streamlines are shown in Fig. 3. Residence times along these streamlines vary from 65 years for the topmost streamline to 165 years for the lowest streamline.

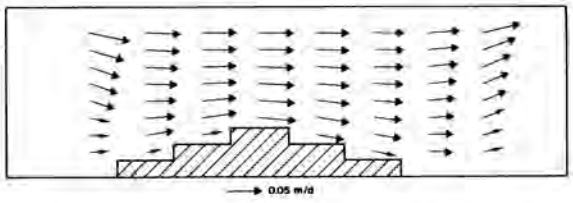

Fig. 2. Steady state velocities: constant liquid density.

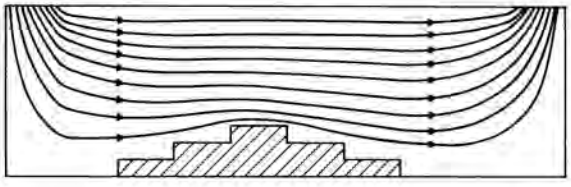

Fig. 3. Steady state streamlines: constant liquid density.

Travelling times from points close to the (right hand side of the) salt dome to the outflow point have also been calculated. The flow paths, not shown in the figure, are strongly influenced by the rectangular shape of the salt dome. The residence times along these streamlines vary from 180 years to 250 years.

Linear Liquid Density: Partly Explicit

Using Eq. (1) to define the liquid density as a function of the mass fraction brine, and defining the fresh water density ρ_f = 1000 kg/m^3 and the brine density ρ_b = 1200 kg/m^3, the simulation was repeated with the existing model [2,3] in order to demonstrate the effect of the liquid density. Although the steady state distribution of the mass fraction brine as shown in Fig. 4 looks reasonable, the flow field as calculated with Darcy's Law and shown in Fig. 5 does not. Treating the liquid density partly explicit, clearly results in numerical instabilities. Streamlines calculated from the velocity given in Fig. 5, show that part of the water entering the model is "catched" in the model and does not reach the outflow boundary.

Linear Liquid Density: Fully Implicit

The simulation with the liquid density, a linear function of the mass fraction brine has been repeated; this time, however, treating the liquid density fully implicit. The resulting distribution of the mass fraction brine, shown in Fig. 6, is somewhat different from the one obtained in the previous calculation. The velocity field, however, does not show the effect of the numerical instabilities. From the velocity field, streamlines from inflow to outflow point have been determined. These streamlines are shown in Fig. 7.

In this case, groundwater flow is more or less restricted to the upper part of the model, much more than in the case of a constant liquid density. The travelling times along the streamlines vary from 65 years to 460 years. Along the top of the model, the

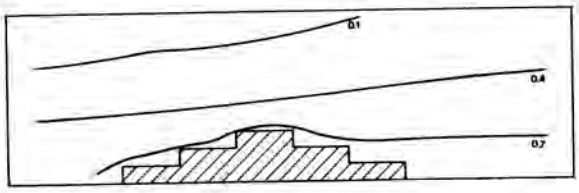

Fig. 4. Mass fraction brine: explicit liquid density.

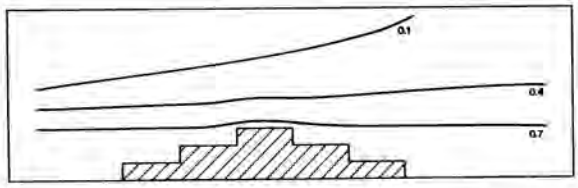

Fig. 6. Mass fraction brine: implicit liquid density.

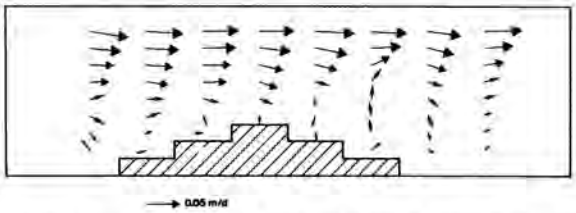

Fig. 5. Velocity field: explicit liquid density.

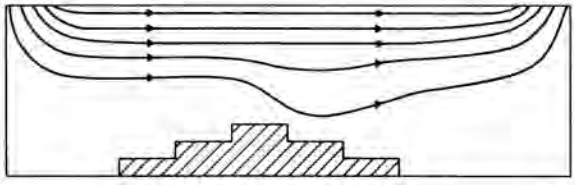

Fig. 7. Streamlines: linear liquid density.

travelling time is a fraction smaller than in case of constant density, while for the lowest streamline, the travelling time is 2.8 times larger. For flow lines starting close to the right hand side of the salt dome, travelling times to the outflow point vary from 435 years to 610 years, which is 2.4 times the travelling time in case of a constant liquid density.

Quadratic Liquid Density

Using the linear relation (1) for the liquid density as a function of the mass fraction brine gives a maximum deviation of 5% from the real liquid density[4]. By describing the liquid density by an (empirical) quadratic function, the maximum deviation can be reduced. Figure 8 shows for both cases the liquid density as a mass fraction of brine.

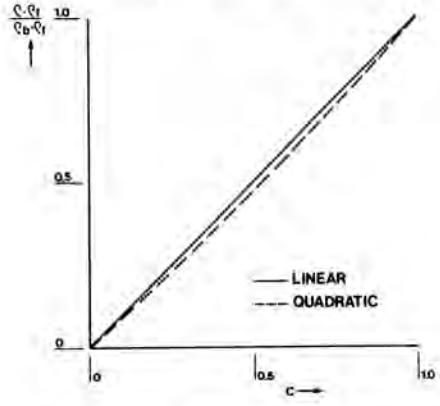

Fig. 8. Liquid density as a function of the mass fraction of brine.

Calculations were repeated using the improved definition of the liquid density. The resulting distribution of the mass fraction brine and the flow pattern are only slightly different from the ones obtained with the density and linear function of the mass fraction brine (Fig. 6 and 7). Differences, however, are found in the travelling times. For streamlines from the inflow point to the outflow point, residence times vary from 65 years to 510 years. For streamlines starting at the right hand side of the salt dome, travelling times to the outflow point vary from 500 years to 820 years, which is on the average 25% larger than in the previous case.

Summary of Results and Conclusion

From the results of the different simulations, it can be concluded that the liquid density plays an important role. Expecially the travelling times, and hence the transport rates, are strongly influenced by variations in the liquid density. Table I summarizes the calculated travelling times for the different simulations.

TABLE I

Travelling Times to Outflow Point
(In Years)

	From Inflow	From Salt Dome
Constant Density	65-165	180-250
Linear Density	65-460	435-610
Quadratic Density	65-510	500-820

Even small changes in the liquid density have a very pronounced effect on the travelling times. A 5% change in density can result in a 25% change in the travelling times. Consequently, in order to describe the flow field in the vicinity of the salt dome reasonably correct, an accurate definition of the liquid density is required.

ACKNOWLEDGEMENT

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