THE PRINCETON GEOTHERMAL RESEARCH PROGRAM

George Pinder
Department of Civil Engineering
Princeton University
Princeton, N.J. 08540

The research program currently underway in the Department of Civil Engineering at Princeton University can be subdivided into five separate interacting components. Each component addresses a specific problem encountered in the numerical simulation of geothermal reservoirs. In this summary, the components will be examined independently although in fact there are many facets of the work which overlap and thereby provide a foundation for the exchange of ideas between individuals.

The natural extension of the two-dimensional single phase areal model of the Wairakei reservoir is the fully three-dimensional problem. Although the development of a three-dimensional finite element energy transport code was re atively straighforward, the cataloguing, organization and manipulation of the large quantities of pertinent field data was more difficult. In preparing the input data trend surfaces of the important hydrological and geologica parameters were generated. In this way the required information for each f nite element node can be determined readily. The simulator is currently operational and the last elements of data are being prepared.

While the correct formulation of the equations governing multi-phase (steam-water) flow in porous media is now available in the literature, the development of an accurate and efficient three-dimensional simulator still remains a formidable task. Because of the flexibility and accuracy of the finite element-Galerkin approach, this method has been chosen as the basis for our general simulator. To overcome limitations inherent in the classical finite-element approach, highly eff cient coefficient generating schemes are combined with iterative methods for the solution of the resulting large systems of algebraic equations.

Although the Biot system of equations based on the theory of elasticity is generally recognized as a r gorous expression of the physics of subsidence, it does not describe impor ant phenomena observed in the field. In particular, it is observed that physical systems are characterized by parameters which exhibit memory. A correct formulation of the problem, therefore, must be based upon visco-elastic rather than elastic theory. Because of the lack of understanding of the exact form of the stress-strain relationship, we have assured generality by considering an approach which extracts the form of this equation directly from available laboratory experiments rather than dictating it a priori. The resulting system of equations is solved using the laplace transform in conjunction with a finite element-Galerkin scheme.

Although equations for energy transport in porous media have been in use for some time, we deemed it necessary to verify that these equations had a sound theoretical basis. A systematic technique of local volume averaging of the continuum equations was adopted and applied to the thermal energy equation. This technique allows one to derive an equation for each phase which contains terms accounting for mechanical dispersion, interphase energy conduction and phase change.

When the assumption of thermal equilibrium between the various phases is reasonable, the equations for each phase may be added together and the coupling terms between the phases will drop out. However, if conditions are such that thermal equilibrium is not established, appropriate constitutive relations can be found for the coupling term and the equations are solved separately for each phase.

For the case of cold water injection into a fractured geothermal reservoir, one might expect the cold water to move at different velocities in the fractures and pores and thermal equilibrium between the pore and fracture fluid may not exist. To model this case, the pore fluid and fracture fluid were considered to be different phases and flow and energy equations were developed for each of the two fluid phases as well as for the solid matrix. At present, a Galerkin-finite element computer code is being developed which solves the complete coupled set of equations. The unknown variables are expanded in terms of a new type of basic function which allows for increased accuracy and a reduction in the number of finite element equations which must be solved.