GEOPRESSURED GEOTHERMAL RESERVOIR ENGINEERING RESEARCH AT THE UNIVERSITY OF TEXAS

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To date, our research has consisted of designing reservoir simulators capable of modeling the behavior of geopressured geothermal reservoirs. The only model we currently have operational is a single phase (water) multi-dimensional simulator of such reservoirs. The model is a finite difference solution of the momentum transport equation for water. The model is two-dimensional, and either areal or cross-sectional studies can be run. The model allows for heterogeneous, anisotropic porous media. The effects of pore pressure reduction on fluid properties and reservoir parameters are included. Reservoir parameters include porosity, permeability, and formation thickness. Even though the presence of dissolved gas is not included in this model, its effects on momentum transport can be approximated by modifying the fluid compressibility.

We plan to use the model to examine the effects of rock compression and shale water influx on the performance of a well completed in a representative Gulf Coast geopressured geothermal reservoir. This will be done to aid in planning well design and production tests for an expected pilot well drilled into such a reservoir.

At this time, we visualize that a geopressured geothermal reservoir might appear like Fig. 1. A massive undercompacted sandstone body is bounded on the landward side by a growth fault. Seaward the formation grades into an undercompacted shale. At the top, the sandstone is bounded by a shale that allows no vertical movement of fluid. Below the sandstone there is an under-compacted shale. The fluid contained within the reservoir is a relatively fresh water. Hopefully, it is contaminated with natural gas in solution.

The sandstone body tends to be elongated in the direction parallel to the ancient seacoast. The body will be an ancient sandbar or delta made up of sediments deposited by the ancient rivers.

We feel the following phenomena will be important considerations in the development of reservoir simulators for the geopressured geothermal reservoirs:

Because of the depositional conditions, the reservoirs are hetero-geneous. There is considerable evidence that shale water influx has played a role in the maintenance of reservoir pressures in gas wells completed in geopressured formations. The first attempts to examine shale water influx will be done by extending the modelled reservoir volume to include the off-shore shales. Both the shales and the sandstones will probably be aniso-tropic as well as heterogeneous.

Since the formations are undercompacted, as fluid is removed the reser-voir will compact as the rock matrix assumes the overburden load. This com-paction will provide a source of depletion energy for the reservoir. It will also reduce the cross-sectional area available for fluid movement and decrease the porosity and permeability of the formation.

The primary reservoir fluid is, of course, water. The temperature is expected to range from 300 to 400° F (150 to 200° C). The formations will be at about 14,000 feet (4,200 meters) in the Texas Gulf Coast. Therefore, hydrostatic conditions will be sufficient to keep the formation water in the liquid state during production.

The dissolved gas is an interesting complication. The mass of dissolved gas per unit mass of water is quite small at full saturation even at the elevated pressures and temperatures associated with geopressured reservoirs. If the formation water is fully saturated with natural gas, as soon as production begins this gas will evolve from the water. It is clear that total removal of the gas in solution will not result in a large gas saturation. The mobility of this gas coming out of solution is not known. For the purposes of reservoir simulation, the prudent approach appears to be to provide for the transport of the natural gas specie as either solution gas or as "free" gas.

If the reservoirs were simply to be depleted, the solution of the differential equations describing momentum transport for the formation fluids would be sufficient to model the behavior of geopressured geothermal reservoirs. However, it is certain that one of the exploitation schemes considered for such reservoirs will be the re-injection of the produced water into the reservoir after it has been "cooled" and "stripped" of the natural gas by the surface installation.

The re-injection of the "cooled" water makes it necessary to include the effects of thermal energy transport in the reservoir. We assume that the reservoir fluids and the rock matrix will be in thermal equilibrium. With reservoir temperature as a variable, fluid and rock properties will exhibit complex behavior.

The differential equations we feel describe the behavior of geopressured geothermal reservoirs are given as Appendix A at the end of this paper.

The boundary conditions for these equations deserve some comment. They will, of course, depend on the modeling study performed and the choice of the system to be represented.

At the top of the reservoir the vertical permeability of the shales will be extremely small. Over the productive life of the reservoir, fluid movement in or out of the reservoir can be neglected at this boundary. At the bottom of the reservoir there may be shale water influx. This can be handled in one of two ways. The most straightforward scheme would be to extend the reservoir system far enough into the shales that a specified potential or no-flow boundary might be specified. This will require a large computing grid. To reduce computer storage, it may be desirable to confine the computing grid to the sand body itself. In this case, the point source terms in the differential equations can be used to represent fluid influx. At the offshore boundary similar conditions can be applied. Along the growth fault, we expect that the boundary will be sealed. If production seems to indicate otherwise, we feel we can use the source terms to represent water influx. We anticipate handling the energy equation boundary conditions in a similar fashion.

APPENDIX A

DIFFERENTIAL EQUATIONS OF FLOW IN GEOPRESSURED GEOTHERMAL RESERVOIRS

Momentum Conservation

Water

$$\nabla \cdot \left[\frac{k_{rw} \bar{\bar{K}} \rho_w}{\mu_w} \nabla (P_w - \rho_w gh) \right] + Q_w = \frac{\partial}{\partial t} (\phi S_w \rho_w) \qquad (1)$$

Gas

$$\nabla \cdot \left[\frac{R_s k_{rw} \bar{\bar{K}} \rho_w}{\mu_w} \nabla (P_w - \rho_w gh) \right] + \nabla \cdot \left[\frac{k_{rg} \bar{\bar{K}} \rho_g}{\mu_g} \nabla (P_g - \rho_g gh) \right]$$

$$+ Q_g = \frac{\partial}{\partial t} (\phi S_w \rho_w R_s + \phi \rho_g S_g) \qquad (2)$$

Energy Balance

$$-\nabla \cdot [\phi S_w \rho_w H_w \bar{U}_w + \phi S_g \rho_g H_g \bar{U}_g] + \nabla \cdot [\bar{\bar{K}}_m \nabla T]$$

$$+ Q_w H_w + Q_g H_g = \frac{\partial}{\partial t} (\phi S_g \rho_g H_g + \phi S_w \rho_w H_w + (1-\phi) \rho_r H_r) \qquad (3)$$

Variable Definitions

k_{rw}, k_{rg} = relative permeability to i^{th} phase.
i = g (gas), i - w (water), i - r (rock)

$\bar{K}$ = local rock permeability tensor

ρ_w, ρ_g = fluid density

μ_w, μ_g = fluid viscosity

P_w, P_g = pressure

g	= gravitational acceleration
h	= local elevation above a reference datum
Q_w, Q_g	= point source
ϕ	= porosity
S_w, S_g	= fraction of pore volume occupied by phase
R_s	= gas in solution per unit mass of water
H_w, H_g	= internal energy of i^{th} phase
U_w, U_g	= superficial (Darcy) velocity
a	= rock-fluid mixture thermal conductivity
T	= rock-fluid temperature

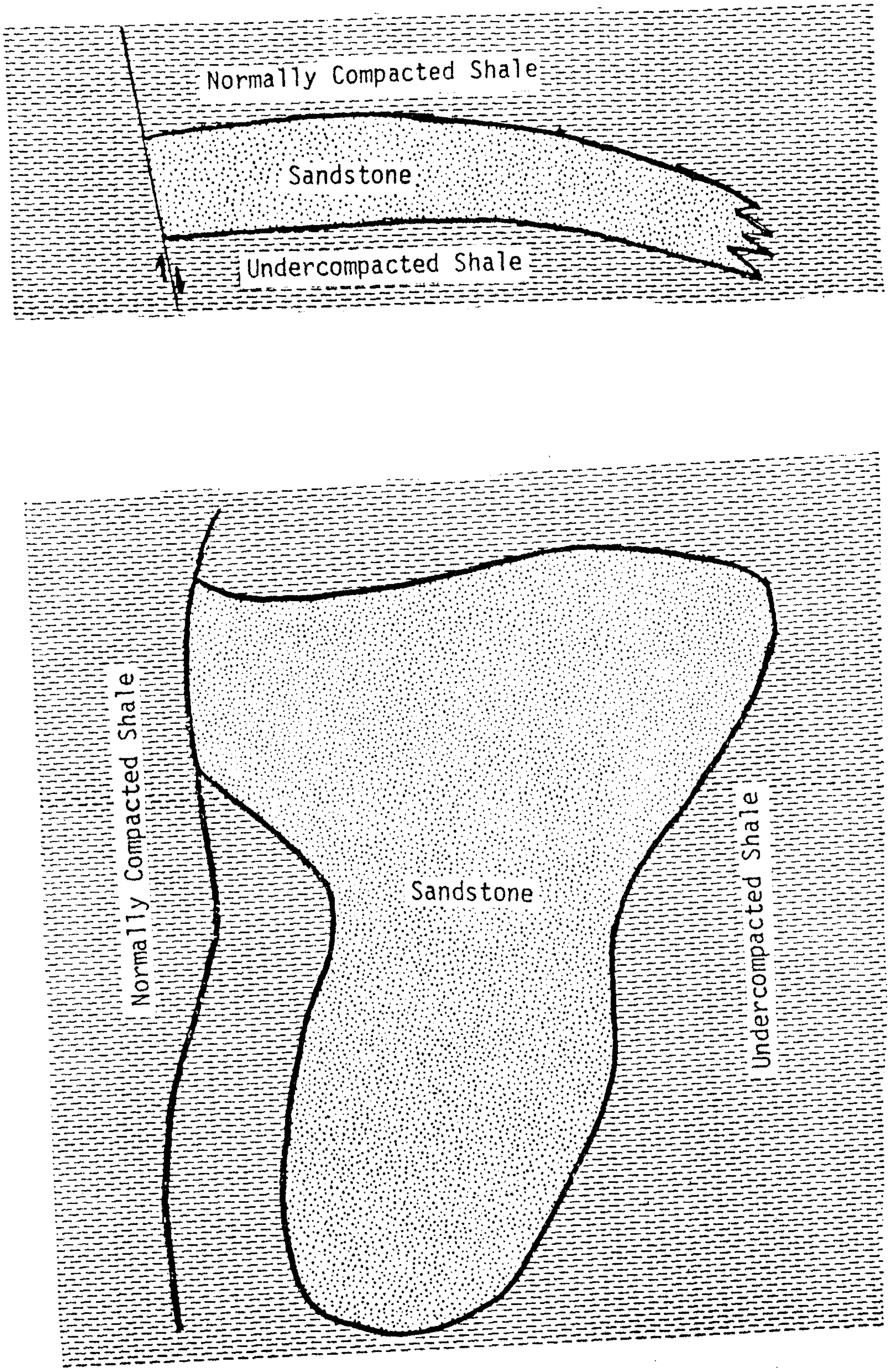

Figure 1 **Cross-section and** Plan View of **Geopressured Reservoir**