TRANSIENT PRESSURE ANALYSIS IN GEOTHERMAL STEAM RESERVOIRS WITH AN IMMOBILE VAPORIZING LIQUID PHASE -- SUMMARY REPORT

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Introduction

The application of transient pressure analysis methods to vapor-dominated geothermal systems has generally been done using methods developed for noncondensable gas reservoirs. These methods have been satisfactory in many cases; however, because they neglect effects of vaporization and condensation, the results may be misleading. The study presented here was motivated by a perceived potential need to incorporated phase changes into the analysis of pressure drawdown and recovery data. It is hoped that this will allow for an increased understanding of the processes occurring in geothermal systems where steam and liquid water are thought to coexist.

A finite-difference model for the horizontal, radial flow of steam in the presence of an immobile vaporizing or condensing liquid phase was adapted from the model of Moench (1976). Results were generated for real physical parameters, and are presented in terms of standard dimensionless pressure (actually pressure-squared) and time groupings. The analysis assumes an initial constant temperature and pressure in the aquifer and an initial uniform liquid-water distribution which partially fills the void space. It is also assumed that the steam and liquid water in the reservoir are in local thermal equilibrium with the reservoir rocks and that temperature changes occur only in response to phase changes. In the examples which follow permeability, porosity, and well discharge are constant.

Results

The computed pressure drawdown plotted in figure 1 (P_D vs. log t_D) shows the comparison of dry steam (S=0.0) with three examples having different quantities of initial liquid-water saturation (S=0.05, S=0.10, S=0.20). The latter results are displaced, as a group, from the response for dry steam by an amount which depends upon the heat capacity per unit volume of the reservoir rock. The slope of the straight line obtained for dry steam is that predicted by the line-source solution to the diffusivity equation.

Figure 2 shows interference pressure drawdown data (log P_D vs. log t_D/r_D^2) compared with the line-source solution. The slight displacement of the results for dry-steam to the left of the line-source solution at early time is due to the spatial increments used in the finite-difference model.

Figure 3 shows Horner buildup graphs (P_D vs. $(t_o + \Delta t)/\Delta t$) for three different values of initial liquid-water saturation. Production time is the same for each case and is approximately 9 hours in duration. Initially (small Δt) the pressure rises rapidly because the steam is superheated in the vicinity of the production well. This is followed by a period during which the pressure is nearly constant owing to the onset of condensation. Continued rise in pressure as time goes on (large Δt) is due to heating by condensation. The location of the plateau in figure 3 depends upon the heat capacity per unit volume of the reservoir rock and upon the amount of liquid which was available for vaporization per unit volume during the period of production.

Discussion

Drawdown data generated with the two-phase simulation model for radial flow to a discharging well shows that the existence of a vaporizing liquid-water phase is manifested on plots of dimensionless time only by a shift in the horizontal direction from the dry steam case. This can be explained as an apparent increase in compressibility of the system. Assuming the validity of the assumptions of this analysis, this result suggests that the presence of a vaporizing liquid will not complicate evaluation of the reservoir permeability-thickness product from drawdown data when the usual methods of gas reservoir engineering are applied. However, this also implies that such a test cannot distinguish between the presence or absence of liquid in the pore space.

Simulated pressure buildup data, on the other hand, show characteristics which are markedly different from that expected for noncondensable gas. Condensation holds the pressure at saturated-vapor pressure and is responsible for the zone of nearly constant pressure seen in the pressure buildup graphs. If phase change plays an important role in pressure transient well testing, it should be manifested in pressure buildup tests.

Details of this analysis will become available in a forthcoming paper by the authors. Further studies are underway that will change some of the assumptions made herein.

Notation and Definition of Dimensionless Groups

P_D	dimensionless pressure squared $= \frac{\mu k h M_w}{q \mu Z_i R T}(P_i^2 - P^2)$	t_D	dimensionless time $= \frac{k P_i t}{\phi \mu r_w^2}$
r_D	dimensionless distance $= \frac{r}{r_w}$	S	liquid-water saturation (percent of void space)
r	radial distance	t	time
r_w	well radius	t_o	production time
q	production rate	Δt	time since shut-in
P	pressure	μ	steam viscosity
P_i	initial pressure	Z_i	initial compressibility factor
k	permeability	R	gas constant
h	reservoir thickness	T	temperature
M_w	molecular weight water	ϕ	porosity

Values of Parameters Used

P_i	30×10^6 dynes/cm^2	M_w	18 g/Mole
k	7×10^{-8} cm^2	μ	1.8×10^{-4} dyne-sec/cm^2
h	714 cm	Z_i	0.9
q	4.16×10^4 g/s	R	8.3×10^7 dyne-cm/(°C Mole)
ϕ	0.10	r_w	15 cm
T	507 °K	t_o	3.22×10^4 s

Reference

Moench, A.F., 1976, Simulation of steam transport in vapor-dominated geothermal reservoirs, U.S. Geol. Survey Open-File Report 76-607, 43 p.

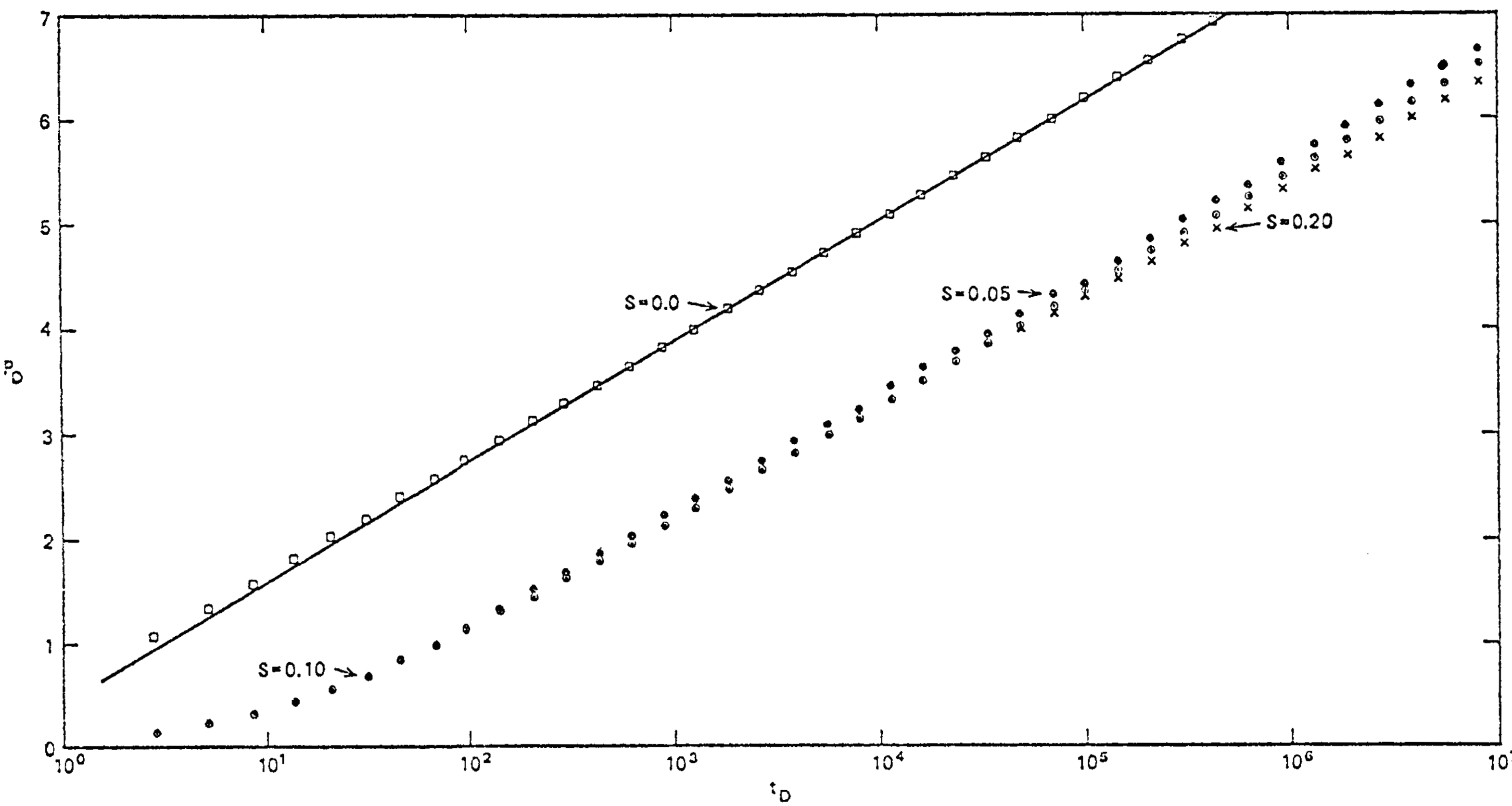

FIGURE 1. Dimensionless pressure drawdown versus log dimensionless time for dry steam (S=0.0) and various values of initial liquid-water saturation.

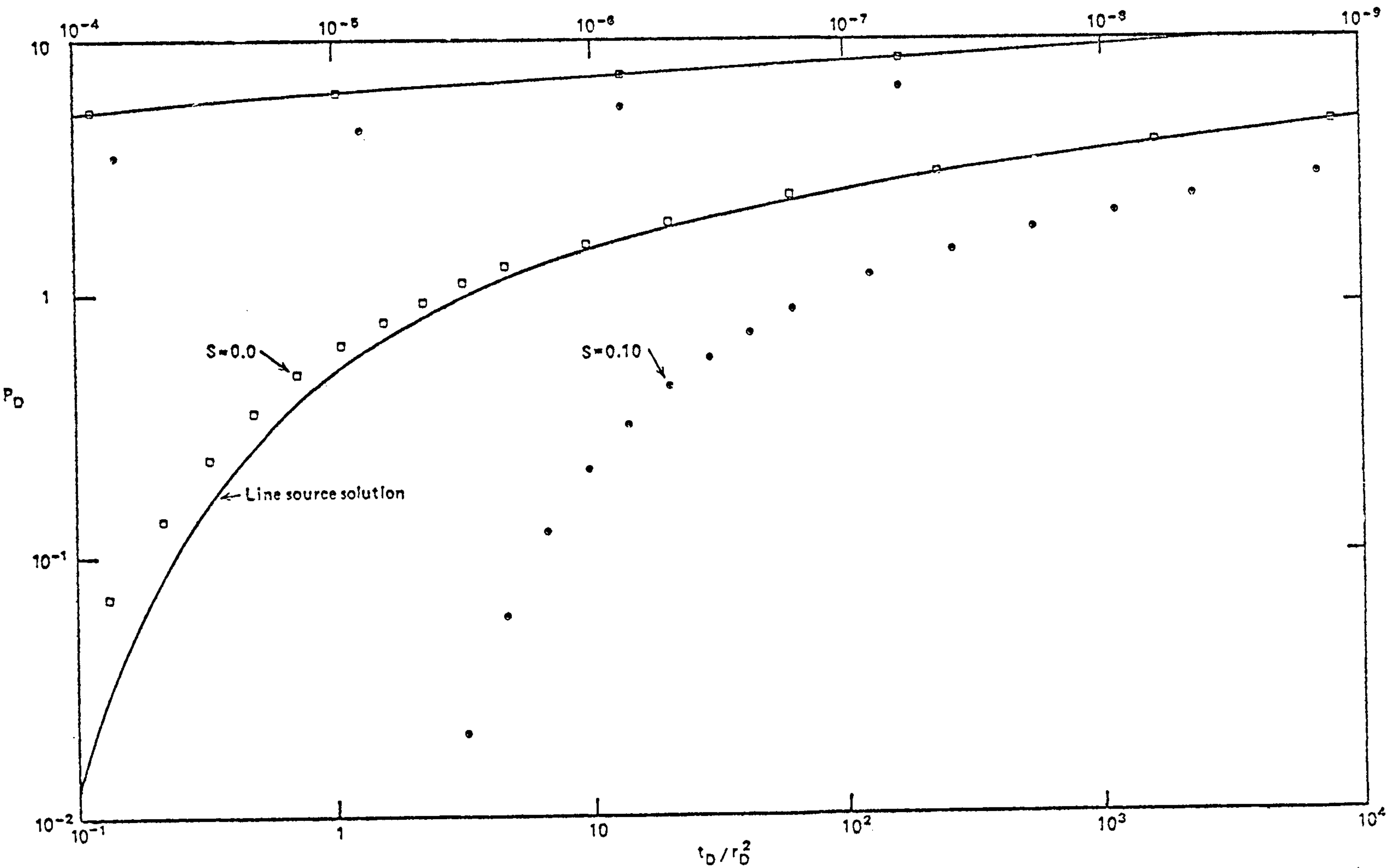

FIGURE 2. Log dimensionless pressure drawdown versus log dimensionless time for dry steam (S=0.0) and one value of initial liquid-water saturation compared with the line-source solution.

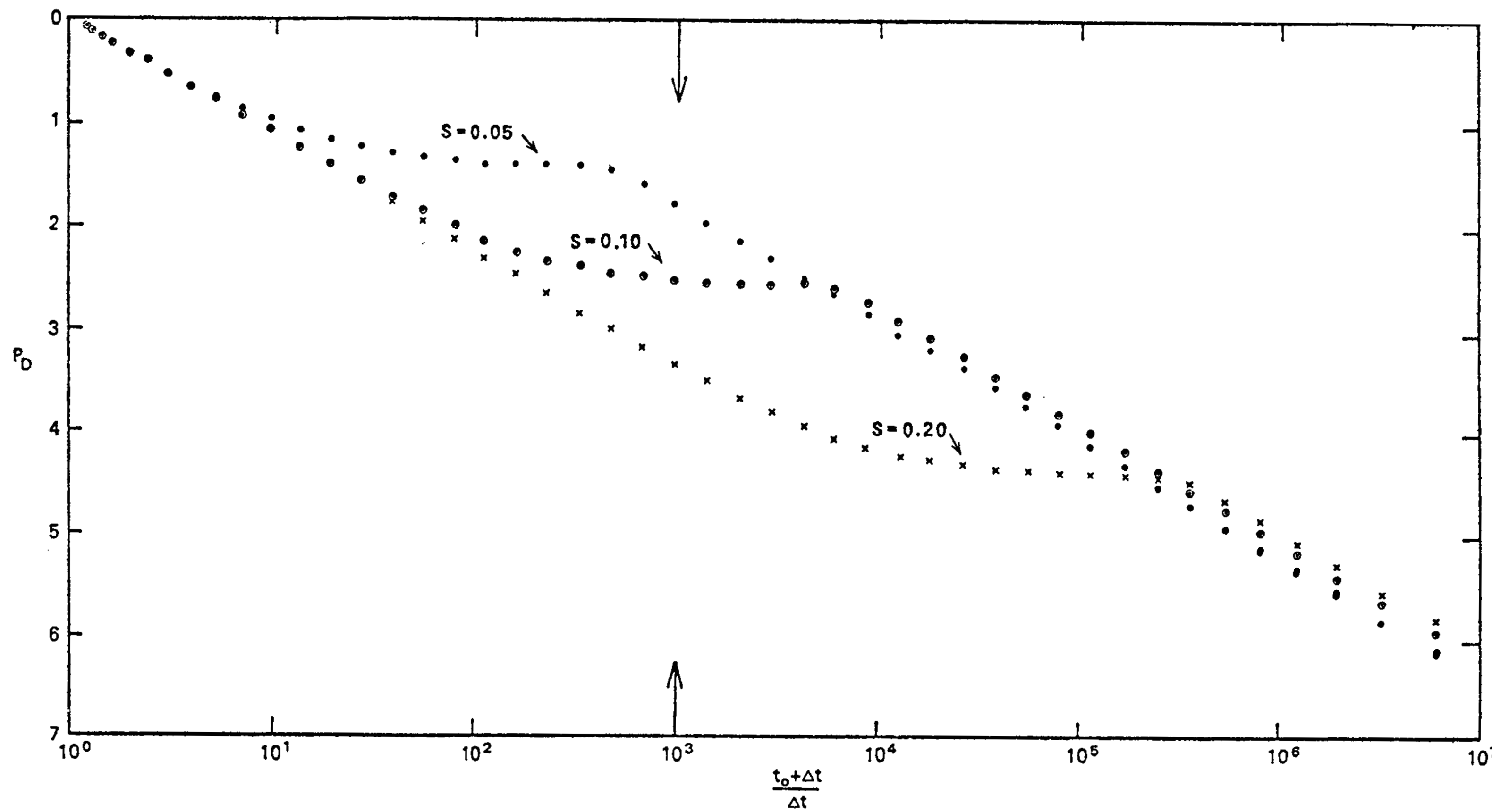

FIGURE 3. Dimensionless pressure buildup vs. Horner time group for various values of initial liquid-water saturation. Arrow on abscissa refers to a real recovery time of 32 s.