Title
THE D.O.E. CODE COMPARISON STUDY: SUMMARY OF RESULTS FOR PROBLEM 4 - EXPANDING TWO-PHASE SYSTEM WITH DRAINAGE

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DISCLAIMER

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THE DOE CODE COMPARISON STUDY: SUMMARY OF RESULTS FOR PROBLEM 4

EXPANDING TWO-PHASE SYSTEM WITH DRAINAGE

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INTRODUCTION

The reservoir in this problem consists of two layers each 1km thick with the upper layer less permeable than the bottom one (detailed properties are given in Table 1). The initial temperature in the reservoir drops linearly from 310°C at the bottom of the reservoir to 290°C at the interface between the two layers and then drops more steeply, but still linearly to 10°C at the ground surface. The initial pressure distribution is the hydrostatic profile corresponding to this temperature distribution.

The reservoir is produced at the bottom of the system at a rate of 100kg/s.km^2. It is assumed that the system and the production are uniform in the horizontal directions so that flow occurs in the vertical direction only.

A calculation grid of 20 equal sized blocks is specified and results are required for a 40 year period.

The anticipated behavior of the reservoir is that a boiling zone will develop near the top of the more permeable layer and spread downwards, also spreading a short distance into the upper layer. As the pressure drops in the lower layer, down flow through the top layer and recharge at the ground surface will be induced.

DIFFICULTIES

The vertical flow of a boiling fluid driven by a combination of gravity and production related pressure gradients is one of the most difficult flow problems for a numerical simulator to handle. Initially the pressure in the reservoir increases rapidly with depth. After production begins the slope of the pressure profile decreases and a liquid/vapor counter-flow develops after about one year when the reservoir starts boiling. That is, water flows downwards to the production well while steam rises and recondenses at a higher level. The numerical analysis required to simulate these physical processes is quite complex. Separate treatment of the vapor flow and the liquid flow is required with upstream weighting of pressure gradient terms in opposite directions for each phase.

At a more elementary level this problem also tests the ability of simulators to handle vigorous boiling (several nodes changing from liquid to two-phase) and the implementation of a constant pressure, constant temperature recharge condition at the ground surface.

RESULTS

The pressure profiles given in Figure 1 show the processes involved clearly. The flow in the top layer does not change very significantly with time and at a rate of approximately 30kg/s.km^2 is not sufficient to supply all the production. Therefore the fluid from the bottom layer is progressively mined. The steeper part of the pressure profile in the lower layer corresponds to the boiling zone. At about 30 years this extends throughout the lower layer and after about 37 years the liquid saturation has dropped sufficiently to inhibit the flow of water and then the pressure gradient steepens to induce an adequate additional downward flow of steam. The steam flow-rate profiles given in Figure 2 show the upward flow of steam changing to a later downward flow at around 37 years.

COMPARISON OF RESULTS

A selection of the required results for problem four are shown in Figures 3,4,5 and 6. The surface recharge results shown in Figure 3 all agree well except for those of Intercomp. Even the Intercomp results are not significantly different. The surface recharge rate is very strongly dependent on the viscosity of water and other parameters at temperatures close to the recharge temperature of 10^{o}C. Therefore, the differences between Intercomp's results and the other results could be explained by minor inaccuracies in their low temperature thermodynamic properties of water. A more detailed comparison of temperatures and pressures at nodes near the surface would be required to fully explain the differences. The production enthalpies shown in Figure 4 are all similar except for those submitted by Intercomp. Their results predict a later rise in the enthalpy, that is a later boiling of the production node. This result is to be expected because of their higher surface recharge rate. Since more cold water flows into the Intercomp reservoir it takes longer for the bottom layer to completely boil.

The pressure and saturation histories at various depths shown in Figures 5 and 6 all agree well (with Intercomp results showing some variation).

CONCLUSIONS

All the simulators compared in this study came through the severe test represented by problem four very well. Clearly they are capable of handling the counter-flow of steam and water, the expansion of a boiling zone and the vertical drainage of cold surface water into a reservoir. As all these processes occur in real geothermal reservoirs such as Wairakei, the results for this problem have considerable practical significance. The simulators tested all appear to be satisfactory tools for analyzing models of this type of geothermal reservoir.

TABLE 1. RESERVOIR PROPERTIES

	Top Layer	Bottom Layer
Porosity	0.15	0.25
Permeability ($10^{-15} m^2$)	5.0	100.0
Rock density (kg/m^3)	2500.	2500.
Rock heat capacity (kJ/kg.K)	1.0	1.0
Thermal conductivity (W/m.K)	1.0	1.0

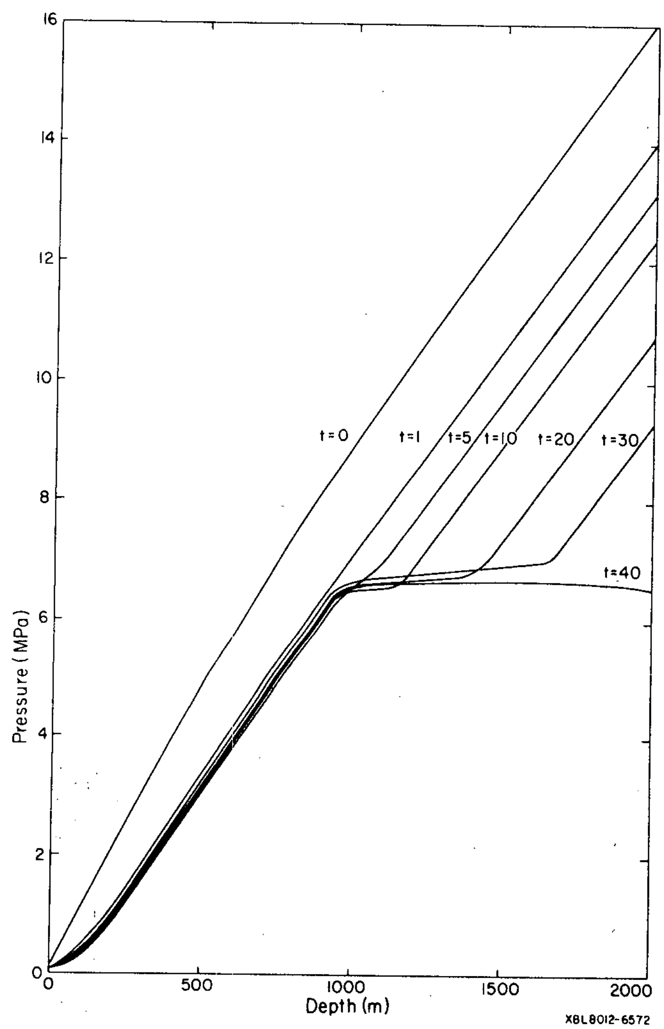

Figure 1. Pressure profiles in the reservoir at various times.

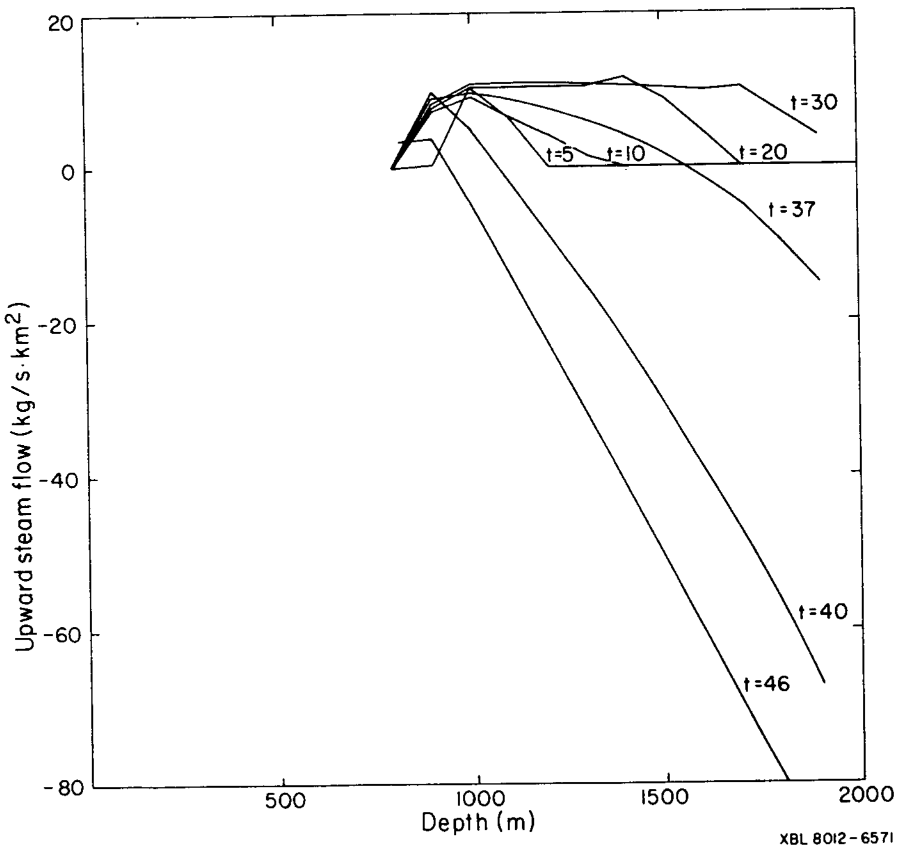

Figure 2. Steam flow in the reservoir at various times.

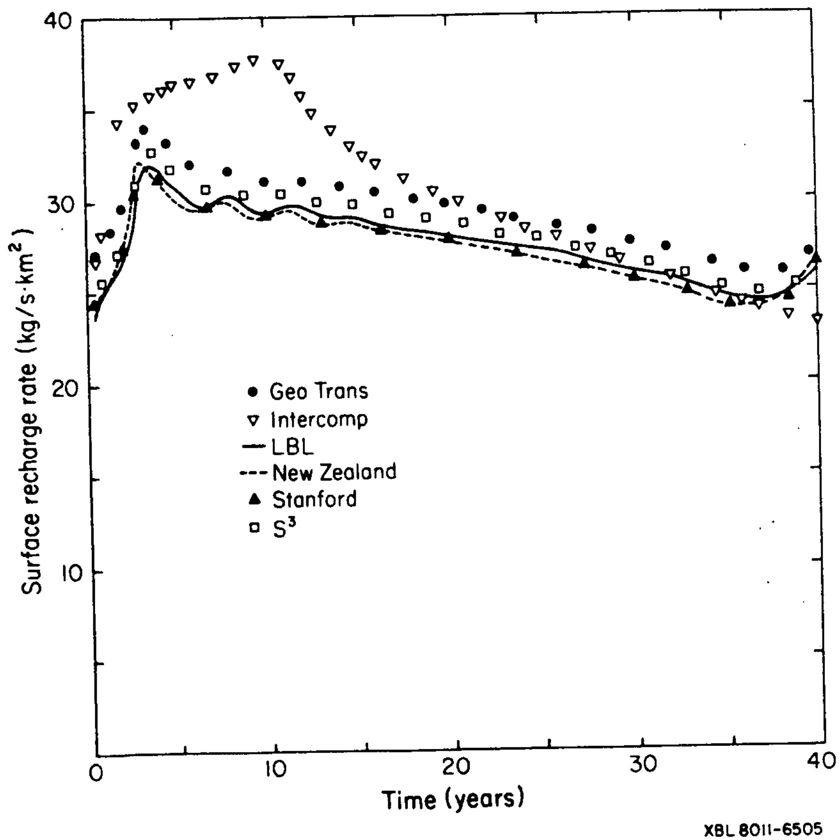

Figure 3. Surface recharge rate.

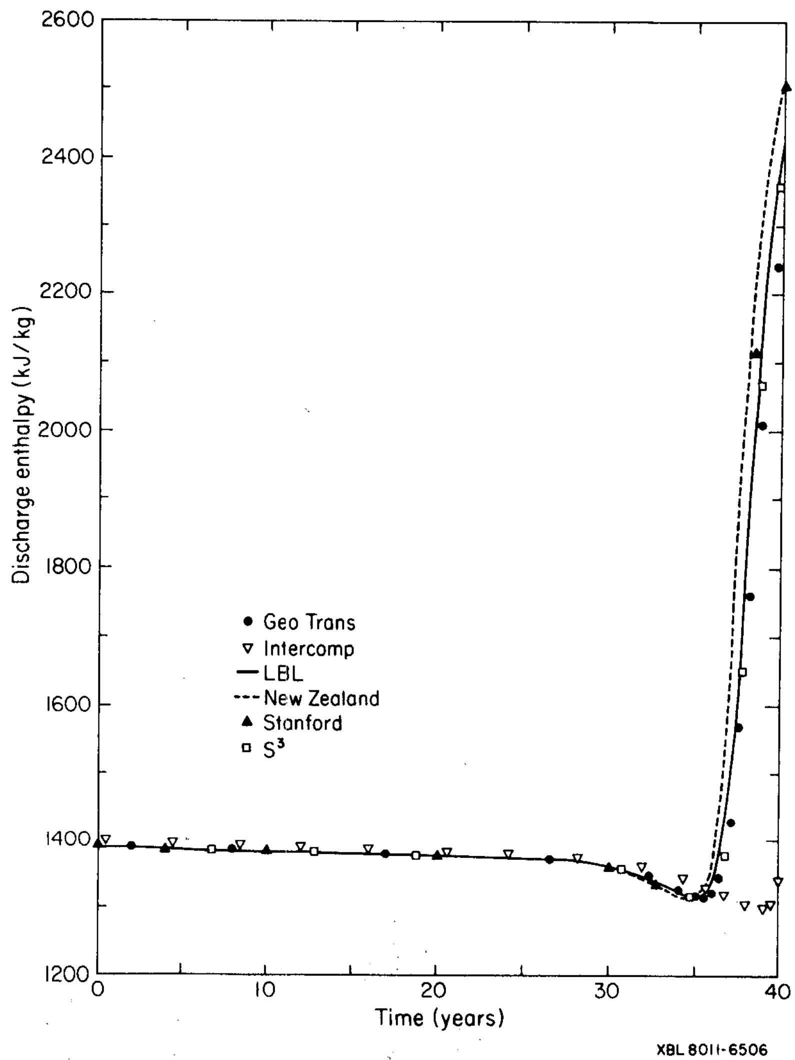

Figure 4. Production enthalpy.

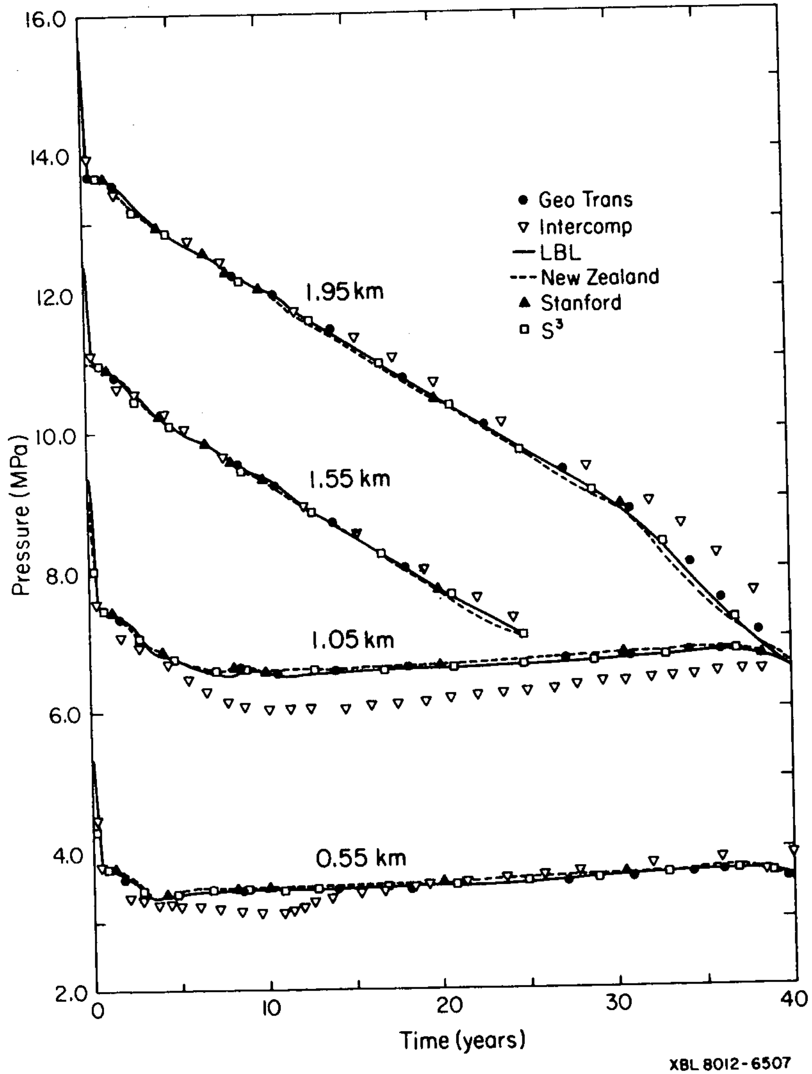

Figure 5. Pressure histories at various depths.

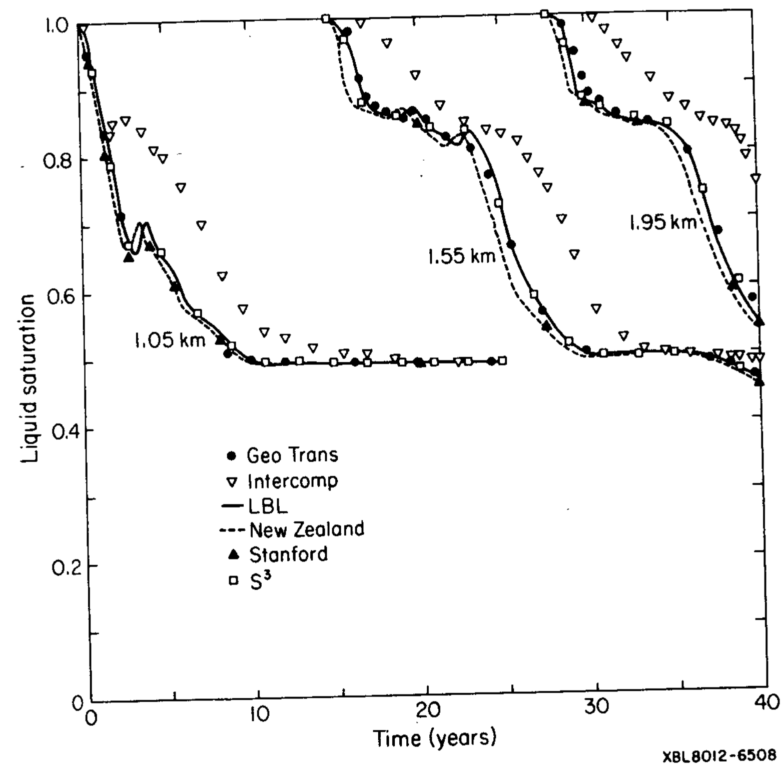

Figure 6. Liquid saturation histories at various depths.

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