EXPERIENCES WITH THE U.S. DEPARTMENT OF ENERGY CODE COMPARISON PROBLEM SET

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ABSTRACT

The program GEOTHNZ, developed at the University of Auckland, is being used to solve a set of six problems specified by the U.S. Department of Energy as part of a project to compare the performance of various computer codes for geothermal reservoir simulation. Preliminary results are reported here.

INTRODUCTION

In late 1979 a U.S. Department of Energy (D.O.E.) sponsored working party met to discuss a reported lack of confidence in geothermal reservoir simulators by engineering consultants to banks, utilities and other investors. At this meeting it was decided that it was important to distinguish the overall geothermal reservoir modelling task from the sub-task of the development of reservoir simulators. As Pritchett (1979) points out in a position paper prepared for the meeting a mathematical model of a geothermal reservoir requires three basic tools: (i) a set of measured data for the system, (ii) a conceptual model based on adequate engineering insight and judgement, and (iii) a reservoir simulator. It was decided therefore that a comparison of reservoir models for a real system would not adequately test reservoir simulators but rather would primarily test the engineering insight of the modellers. Following a suggestion by Pritchett (1979) it was decided that as a first stage of code validation and comparison D.O.E. should set up a small number of idealized problems which would exercise all the features of simulators likely to be required for modelling real geothermal reservoirs. A second working party met in early 1980 to construct the problem set and subsequently D.O.E. issued a request for Proposals (R.F.P) in July 1980 with the aim of encouraging 6-8 groups to submit solutions to the problem set by 15th November 1980. The results of the project will be discussed at the Stanford Geothermal Reservoir Workshop in December 1980.

Because of the short time available it was not possible for any New Zealand group to submit a proposal for the code comparison study before the specified deadline but the problem set was obtained by the University of Auckland reservoir simulation group and is currently being solved.

PROBLEM SET

The complete specification of the problem set is contained in the D.O.E. RFP (1980). The basic idea behind the construction of the problem set was to test the capability of the codes to simulate both one-phase, two-phase and flows with phase transitions in various geometrical configurations.

Problem 1: (1-D Avdonin solution)
This problem involves one dimensional, radial, flow of heat by conduction and convection in single-phase compressed water. The parameters of the problem were chosen to allow the comparison of numerical results with an analytic solution produced by Avdonin (1964).

Problem 2: (1-D Well test analysis)
This problem is really three problems. It involves the radial flow of fluid to a well for (a) liquid water, (b) a boiling two-phase mixture of steam and water, and (c) a flashing flow. In the case (a) a comparison of results can be made with the well-known Theis solution and for (b) and (c) a quasi-analytic solution developed by one of the authors (O'Sullivan, 1980) is available.

Problem 3: (2-D flow to a well in fracture/block)
This problem is designed to represent a well test in a fractured reservoir. Radial, horizontal flow to a well in a fracture is linked to vertical flow in a low permeability block.

Problem 4: (l-D vertical two-phase flow)
This problem involves l-D flow under both single-and two-phase conditions. A two layer reservoir in an initially liquid hydrostatic state is produced at its base. Boiling occurs in portions of the reservoir and cold recharge occurs at the surface of the reservoir.

Problem 5: (Flow in a 2-D areal reservoir)
This problem involves both single-phase and two-phase flow in a 2-D horizontal reservoir. The reservoir is produced at a constant rate at one point and recharged over one of its lateral boundaries (constant pressure). In a second case injection into the reservoir at a second point is also specified.

Problem 6: (Flow in a 3-D reservoir

This problem involves flow within a 3-D system, with production from one corner and constant pressure upper and lower surfaces.

PROGRAM GEOTHNZ

During the last five years a number of different groups have developed geothermal reservoir simulators. Probably the most successful are those developed by:

(i) Lawrence Berkeley Laboratory (Pruess, Schroeder and Zerzan, 1978),

(ii) U.S. Geological Survey (Faust and Mercer, 1979),

(iii) Intercomp(Coats, 1977),

(iv) Phillips (Thomas and Pierson, 1976),

(v) S-Cubed (Garg, Pritchett and Brownell,1975),

All these simulators and GEOTHNZ use finite difference approximations of the governing equations which represent:

(i) Conservation of mass,

(ii) Conservation of energy,

(iii) Darcy's law for the flow of fluid through a porous matrix,

(iv) Thermodynamic formulae.

There are differences in the methods used by the various researchers but most use finite difference schemes which are fully implicit in time and then use the Newton-Raphson method to solve the resulting nonlinear equations.

More completedetails of the numerical methods used in GEOTHNZ are reported elsewhere (Zyvoloski et al., 1979; Zyvoloski and O'Sullivan, 1980; O'Sullivan et al., 1980)

RESULTS

The data for problem 1 are listed in table 1. It was not found possible to take a time step as large as that specified(1.67×10^7s) but otherwise no difficulties were encountered. The graph of the temperature distribution at $t = 10^9$ sec is shown in fig. 1 and the temperature at r = 37.5 m vs time is given in fig. 2. Unfortunately the reference to the Avdonin solution could not be obtained.

The data for problem 2 are listed in table 2. The pressure drawdown curves for problem 2 abc are shown in figs. 3,4, and 5. The numerical solutions show some oscillation with time. This results from the rather unsatisfactory mesh specified. A mesh such as that used by Garg (1978) or a constant volume block mesh would produce smoother results.

The data for problem 3 are listed in table 3. Some modifications of the basic GEOTHNZ program were required to implement zero horizontal permeability in the block and the specified special well block.

Plots of pressure vs log (time) ere shown in figure 6.

Data for problem 4 are listed in table 4.

Some modifications of GEOTHNZ, suggested earlier by its developers (O'Sullivan et al., 1980) were required to allow for correct upstream weighting of flux terms in problem 4 when steam and water are counter flowing. When these were implemented results for the required 40 years were obtained (see figure 7).

At the time of writing work is continuing on problem 5. GEOTHNZ does not presently have a 3D capability and therefore problem 6 will not be solved.

CONCLUSIONS

The program GEOTHNZ is apparently working satisfactorily on solving the D.O.E. code comparison problem set. However comparisons with some analytic results and the results from other codes are required to ensure complete confidence. More complete results will be reported at a later date.

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Table 1 : Data for Problem 1

Initial pressure (MPa)	5
Initial temperature (°C)	170
Porosity	·2
Permeability ($10^{-12}m^2$)	1
Thermal conductivity (W/m.K)	20
Thickness (m)	100
Injection rate (kg/s)	10
Injection temperature (°C)	160
Rock heat capacity (kJ/m^3K)	2500

Table 2: Data for problem 2.

Specification	Case a	Case b	Case c
Initial pressure (MPa)	9.0	3.0	9.0
Initial liquid saturation	1	.65	1
Initial temperature (°C)	260	232.8	300
Porosity	.20	.15	.20
Permeability ($10^{-12}m^2$)	.01	.24	.01
Thickness (m)	100	100	100
Discharge (kg/s)	14.0	16.7	14.0
Rock heat capacity (kJ/m^3K)	2650	2000	2650

Table 3 : Data for Problem 3

Specification	Case a	Case b
Initial pressure (MPa)	3.05	3.05
Initial liquid saturation	0	0.2
Initial temperature (°C)	234	234
Porosity in fracture	.1	.1
Porosity in block	.1	.1
Permeability in fracture ($10^{-12}m^2$)	.3	.3
Permeability in block ($10^{-12}m^2$)	.00003	.00003
Thickness of fracture (m)	.1	.1
Thickness of block (m)	1.0	1.0
Well discharge (kg/s)	.028	.028
Well radius	.16	.16
Rock heat capacity (kJ/m^3K)	2570	2570

Table 4 : Data for Problem 4

Specification	Upper Layer (0 ≤ D ≤ 1 km)	Lower Layer (1km < D ≤ 2 km)
Rock density (kg/m^3)	2500	2500
Porosity	0.15	0.25
Permeability ($10^{-12} m^2$)	.005	.1
Rock specific heat (J/kg K)	1000	1000
Thermal conductivity (W/m.K)	1	1
Initial temperature (^oC)	[10 + 280(D/1km)]	[270 + 20(D/1km)

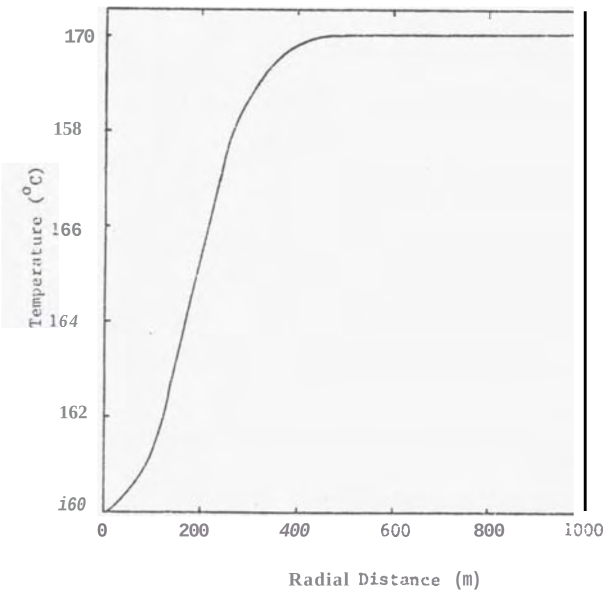

Figure 1. Temperature versus radial distance at 10^9 seconds.

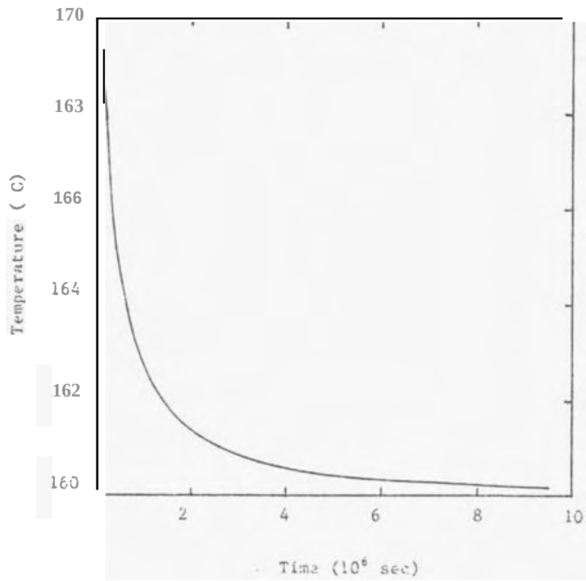

Figure 2. Temperature versus time at r = 37.5m

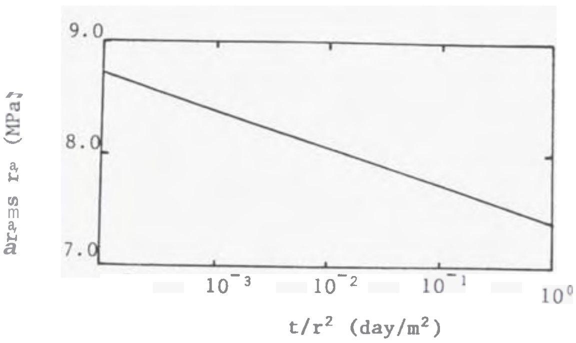

Figure 3. Pressure drawdown curve for problem 2a

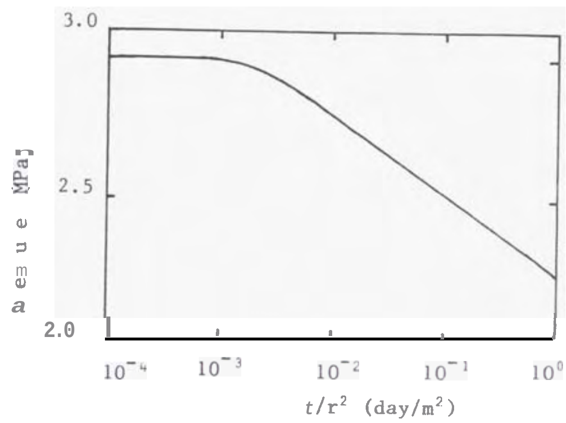

Figure 4. Pressure drawdown curve for problem 2b.

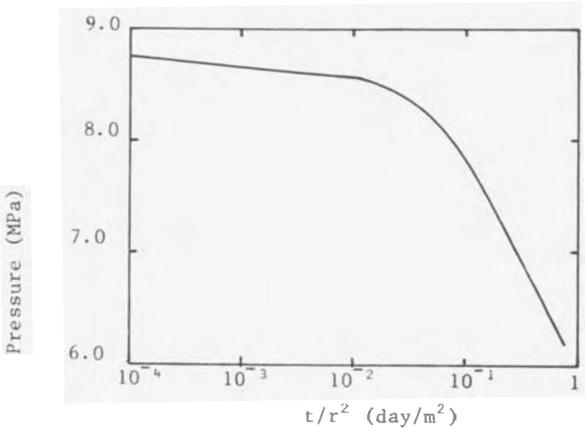

Figure 5. **Pressure drawdown curve for problem 2c.**

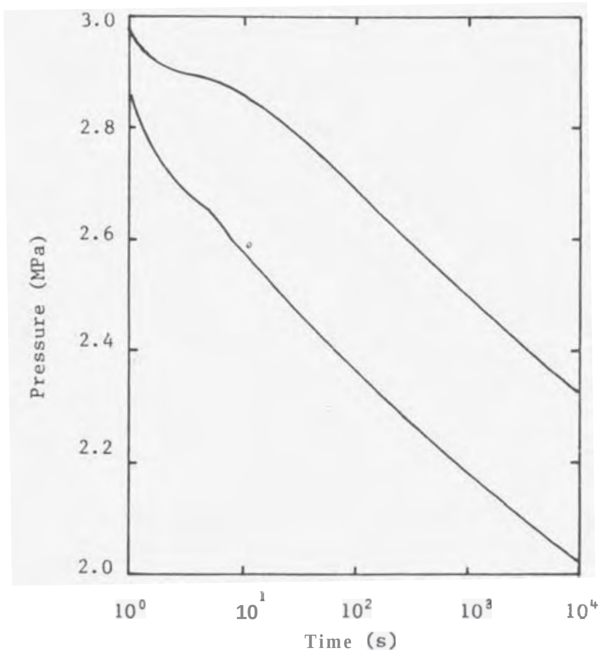

Figure 6. Pressure draw down at well face for problems 3a and 3b.