ANALYSIS OF GABBRO 1 - STEAM PRESSURE BUILDUP TEST

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INTRODUCTION

A pressure-buildup test which was run on a well located in the Gabbro zone (north of the old Larderello field) shows a pressure plateau which may be due to condensation in the reservoir. Analysis of this test makes use of the model proposed by Moench (1978) which assumes that steam vaporizes from thin, highly-permeable, porous fissures that surround blocks of impermeable rock. Heat is transferred from the blocks to the fissures by conduction.

GABBRO 1 TEST DATA

In a search for additional steam to augment the declining production in the Larderello area, several wells were drilled after 1960 in the Gabbro zone (Celati, and others, 1976). In 1962 well Gabbro 1 was successfully completed and a pressure buildup test was run on the well. The well was drilled to a depth of 850 m and cased to the top of the producing formation with a 32 cm diameter casing. Steam is believed to be produced from dolomites and anhydrites located in the depth interval 735-795 m and perhaps also from underlying fractured quartzites and phyllites.

The test was run at a production rate of 110.8 x 10^3kg/h for a period of 389 h. Wellhead pressure and temperature were 5.80 Kg/cm^2 absolute (5.7 bars) and 193 ^oC, respectively, in the first 2 days of the test period. It was assumed that these values held constant for the remainder of the test. Noncondensable gases were present in the amount of 30.4 normal liters per kilogram of steam (about 6% CO_2 by weight).

Bottom-hole pressure and temperature were estimated to be 10 bars and 211 ^oC, respectively, using the results of Nathenson (1975). Consequently, as the steam enters the well it was superheated by about 30 ^oC.

Data from the buildup test are shown in figure 1, in which pressure squared is plotted versus dimensionless time using the usual Horner semi-log coordinates. Calculation of the permeability-thickness product from the straight line (early time) portion of the plot gives a value of approximately 30 darcy-meters. The final shut-in pressure of 30.5 bars corresponds to an equilibrium temperature of 234.5 ^oC assuming negligible influence of both the noncondensable gases and the weight of the static column of steam.

A plausible explanation for the change in steam temperature from 234.5 ^oC in the reservoir to 211 ^oC at the well bottom is that vaporization occurred in the reservoir during steam production.

CONCEPTUAL MODEL

We decided to analyse the data using the model described by Moench (1978) because the shape of the pressure buildup curve in figure 1 shows the presence of a pressure plateau at large recovery times. In this model the reservoir is assumed to be composed of a random assortment of highly permeable, porous fissures separated by blocks of impermeable rock, as illustrated in figure 2a. In this paper the fissures themselves are assumed to be homogeneous porous materials. In the undeveloped reservoir, blocks and fissures, including the liquid and vapor in their porous matrix are assumed to be at the same constant temperature throughout. With the start of steam discharge, pressure reductions induce vaporization of liquid water within the pores of the fissures. The resulting temperature decline in the fissures induces transfer of heat by conduction from the adjacent blocks.

This conceptual model is idealized as shown in figure 2b. Alternating layers of fissures and blocks of constant thickness are assumed to extend in the radial direction to infinity. The thickness of the impermeable block is assumed to represent the average thickness of the blocks in the actual reservoir. The fissures are assumed to be filled initially with a uniform distribution of liquid water and steam at saturated-vapor pressure. The initial water content of the fissure is sufficiently low that changes in saturation do not appreciably change the permeability to steam. Well discharge and fissure permeability, porosity, and thermal properties are assumed constant to simplify interpretation of the results.

The analysis is made with the finite-difference model described by Moench and Atkinson (1978), modified by Moench (1978).

RESULTS AND DISCUSSION

Figure 3 shows the results of the computer simulation compared with the test data. Several trial and error runs were made in order to get this match.

Initial attempts at simulation of the data were not successful because pressure in the well block (radius 16 cm) became negative when known discharge rate and calculated permeability-thickness product, kh, were used. Increasing kh by 10% and providing a negative skin allowed the well bottom pressure to remain above 10 bars. Negative skin was included in the simulation by increasing fissure permeability by a factor of 10 in a 16 cm annulus around the wellbore. Wellbore storage was also included in the simulation. However, wellbore storage effects are negligible after 1-2 minutes of pressure drawdown or buildup.

To apply the conceptual model described above, it was necessary to assume that the porous fissures are thin enough that heat conduction will change their temperature. The position of the pressure plateau in figure 1 shows that the fissure has heated nearly to its original temperature prior to shut-in time. This observation puts constraints on the thickness of the fissure. The heat capacity of the fissure (which is directly related to thickness) must be sufficiently low and the heat transfer rate sufficiently high that the fissure temperature will rise to nearly its original temperature in the time frame of 389 hours.

The parameters used to generate the results shown in figure 3 are listed in Table 1. It was found that the maximum permissible fissure width is about 50 cm when thermal conductivity is assumed to be 8 x 10^{-3} cal/(cm s ^{o}C). Lower thermal conductivities require thinner fissures in order to get the same results. The blocks adjacent to the fissures are large enough that they are effectively infinite reservoirs of heat.

The model draws fluid from only a single fissure, hence the well discharge is reduced by whatever the proposed number of fissures may be. The number of fissures is constrained by the assumed fissure permeability, its thickness, and the total kh product. In computation of the results shown in figure 3, a permeability of 5.5 darcys in 12 fissures intersecting the wellbore gives rise to the required kh of 33 darcy-meters. The position. of the straight line portion of the pressure buildup is sensitive to reservoir heat capacity per unit volume as explained by Moench and Atkinson (1978). As rock specific heat and density do not vary significantly from one rock type to another, reservoir heat capacity depends primarily upon fissure porosity. A porosity of 15% was required to get the match shown in figure 3.

Figure 4 shows the results obtained from simulations using different production times. The curves shift upward and to the right as production time increases. This results is consistent with observations of pressure buildup at the Geysers (Strobel, 1976, p. 145).

Condensation within the wellbore during pressure buildup is a possible complicating factor. It had to be assumed in this analysis that liquid which condensed in the wellbore either drained out the bottom of the well or condensed at a rate sufficiently slow that it accumulated in the 50 m of open hole below the producing horizon without affecting the pressure behavior.

CONCLUSIONS

The successful simulation of the pressure buildup data for Gabbro 1 suggests that this conceptual model, which assumes heat is conducted into highly permeable fissures that are cooled by vaporization, may be a realistic representation of the reservoir. The pressure plateau at the end of the buildup test can be explained by condensation within the reservoir. It is not necessary to invoke isothermal, constant pressure boundaries at some distance away from the production well to explain this behavior.

The parameters used in the simulation give satisfactory results. However, they are not unique. Additional data, such as pressure buildup tests run for different production times and measurements of reservoir thermal properties, would be desirable to corroborate the interpretation given here. Also, bottom-hole measurements of temperature and pressure during buildup would help to resolve the question of possible complications due to condensation within the wellbore.

REFERENCES

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TABLE 1: PARAMETERS USED IN SIMULATION

Fissure permeability	5.5 darcys
Fissure porosity	0.15
Fissure width	50 cm
Number of fissures	12
Discharge per fissure	9.233×10^{3} kg/h
Thermal conductivity	8×10^{-3} cal/(cm s ^{o}C)
Thickness of blocks	1000 cm
Initial temperature	234.8 ^{o}C
Initial pressure	30.5 bars
Initial liquid saturation	0.067
Well radius	16 cm
Well depth	8.5×10^{4} cm
Skin permeability	55 darcys
Rock specific heat	0.23 cal/(g ^{o}C)
Rock density	2.3 g/cm^{3}

NOTE: remaining parameters are the known properties of water at prevailing temperature and pressure.

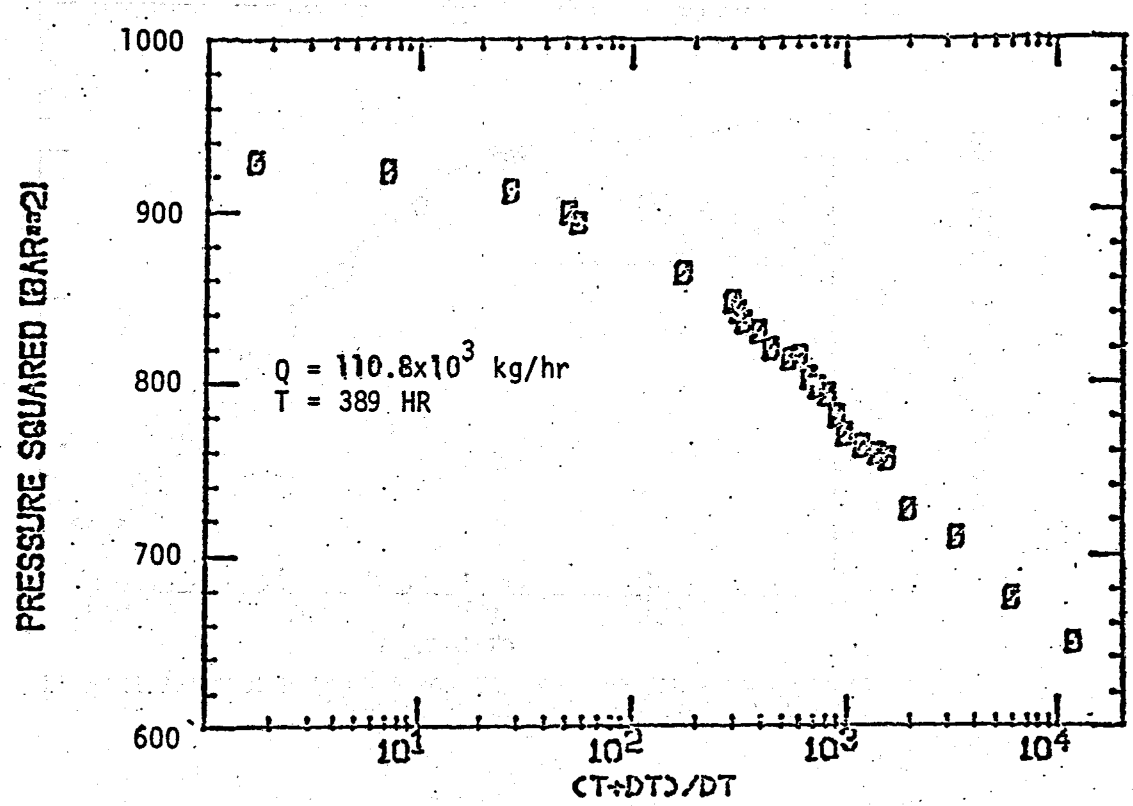

FIG. 1: GABBRO 1 PRESSURE BUILDUP DATA

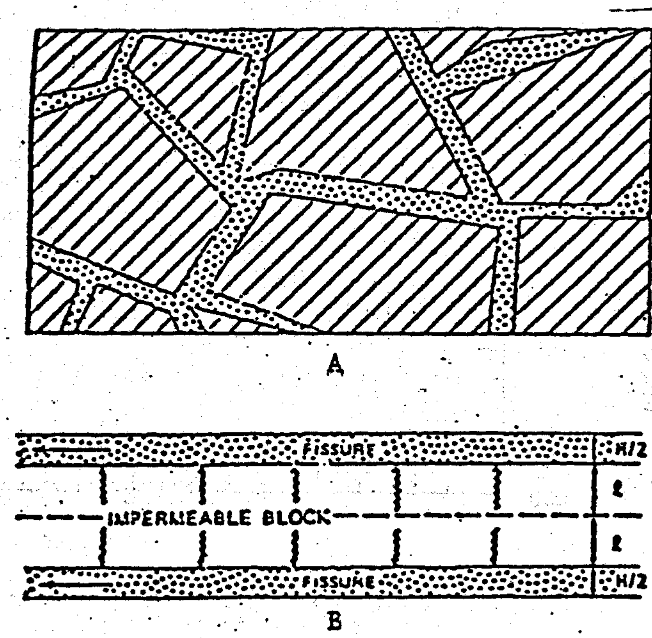

FIG. 2: VAPOR-DOMINATED GEOTHERMAL RESERVOIRS. A: Hypothetical fractured reservoir composed of porous fissures and impermeable blocks. B: Idealized block and fissure reservoir used in the model.

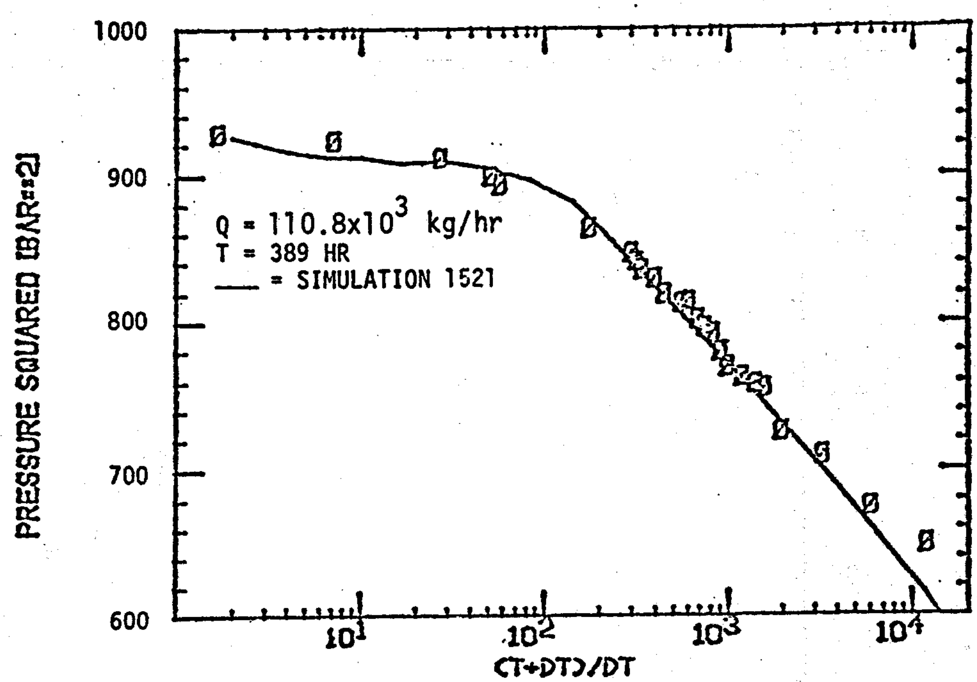

FIG. 3: GABBRO 1 PRESSURE BUILDUP DATA COMPARED WITH COMPUTER SIMULATION RESULTS FOR A PRODUCTION TIME OF 389 HOURS

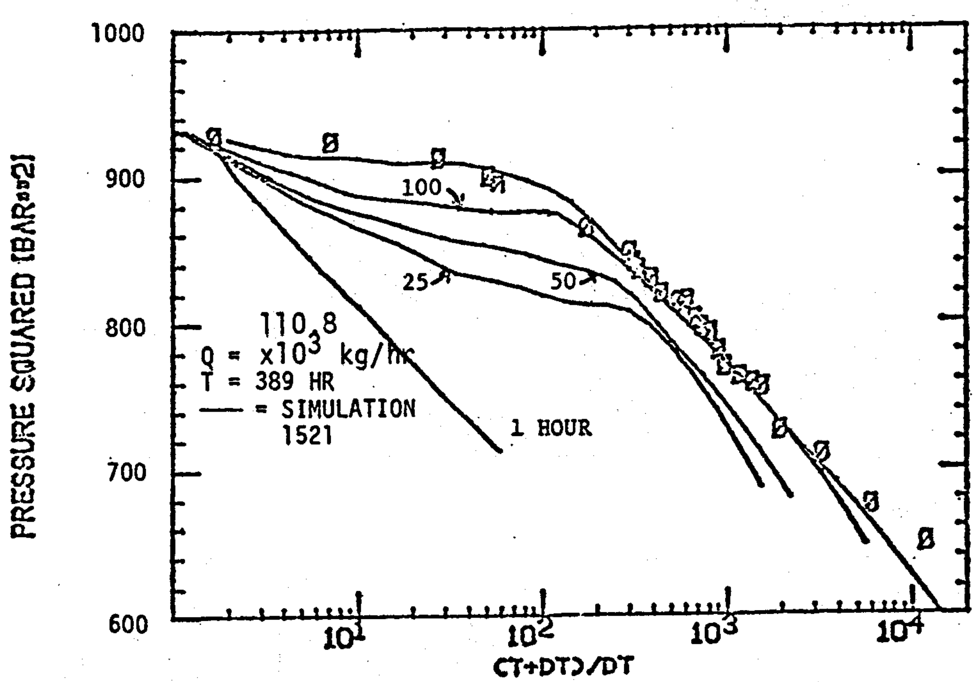

FIG. 4: GABBRO 1 PRESSURE BUILDUP DATA COMPARED WITH COMPUTER SIMULATION RESULTS FOR SEVERAL PRODUCTION TIMES