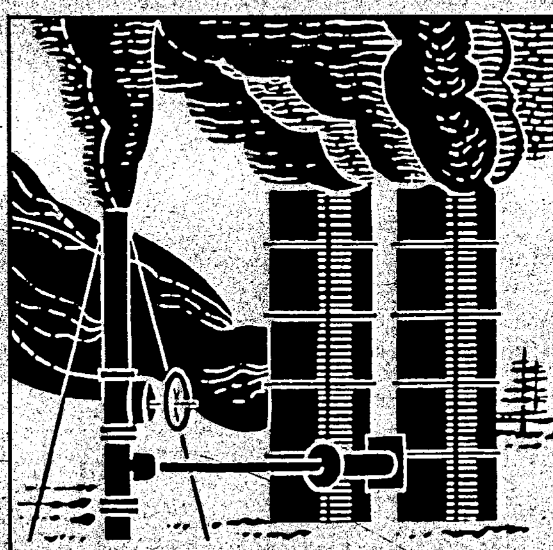
proceedings of THE 17th NEW ZEALAND GEOTHERMAL WORKSHOP 1995



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presented by

Geothermal Institute

The University of Auckland

in conjunction with

The Centre for Continuing Education

DISCLAIMER

USE OF SLIM HOLES FOR GEOTHERMAL RESERVOIR ASSESSMENT: AN UPDATE

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SUMMARY—Production and injection data from slim holes and large-diameter wells in three (3) geothermal fields (Oguni, Sumikawa, Steamboat Hills) were examined to determine the effect of borehole diameter (1) on the discharge rate and (2) on the productivity/injectivity indices. For boreholes with liquid feedzones, maximum discharge rates scale with diameter according to a relationship previously derived by Pritchett. The latter scaling rule does not apply to discharge data for boreholes with two-phase feedzones. Data from Oguni and Sumikawa geothermal fields indicate that the productivity (for boreholes with liquid feeds) and injectivity indices are more or less equal. The injectivity indices for Sumikawa boreholes are essentially independent of borehole diameter. The latter result is at variance with Oguni data; both the productivity and injectivity indices for Oguni boreholes display a strong variation with borehole diameter. Based on the discharge and injection data from these three geothermal fields, the flow rate of large-diameter production wells with liquid feedzones can be predicted using data from slim holes.

1. INTRODUCTION

Since a major impediment to the exploration for and assessment of new geothermal areas worldwide is the high cost of conventional rotary drilling, it would be desirable to be able to utilize low-cost, small-diameter (diameters < 15 cm) slim holes for geothermal reservoir assessment. As a part of its geothermal research program, the U.S. Department of Energy (DOE) through Sandia National Laboratories (Sandia) initiated a research effort to demonstrate that slim holes can be used (1) to provide reliable geothermal reservoir parameter estimates, and (2) to predict the production behavior of large-diameter wells (Combs and Dunn, 1992). To date, the DOE/Sandia slim hole program has consisted of two primary elements, *i.e.*, (1) examination and analysis of slim hole and large-diameter well data from Japanese geothermal fields (Garg, *et al.*, 1995; Garg and Combs, 1995) and (2) drilling of slim holes in several geothermal fields in the western U. S. to compare with offset large-diameter production wells (Finger, *et al.*, 1994; Combs and Goranson, 1995). In this paper, we will summarize the discharge and injection data from both slim holes and large-diameter productions wells at the Oguni and Sumikawa Geothermal Fields in Japan and at the Steamboat Hills Geothermal Field in Nevada, U.S.A.

Brief overviews of the three geothermal fields are given in Section 2. In Section 3, the injectivity and productivity indices for both slim holes and large diameter wells are presented. The variation of discharge rate with borehole diameter is discussed in Section 4. In Section 5, the conclusions for geothermal reservoir evaluation using discharge and injection data from slim holes are presented.

2. OVERVIEW OF THE GEOTHERMAL FIELDS

2.1 Oguni Geothermal Field, Kyushu, Japan

The Oguni and Sugawara Geothermal Fields together comprise the northwestern Hohi geothermal region, northeastern Kyushu, Japan (Figure 1). An area of numerous hot springs, the Hohi geothermal region is located about 40 km southwest of the coastal resort of Beppu, and some 20 km north of Mt. Aso, an active caldera. The Oguni Geothermal Field is characterized by a subsurface stratigraphic sequence of indurated sediments and volcanics overlying a granitic basement.

The Hohi formation and the upper part of the Shishimuta formation constitute the principal geothermal aquifers (Garg, *et al.*, 1995). The feedzone pressures imply the existence of a high pressure zone in the southern part and a low pressure zone in the central and northern parts of the Oguni Geothermal Field. Based on analyses of pressure interference data from low-pressure zone boreholes, the transmissivity is approximately 100-250 darcy-meters; while the high pressure zone has a modest transmissivity of about 15 darcy-meters. The average reservoir temperature at Oguni is about 225°C, while the maximum stable preproduction subsurface temperature of 241°C was measured at total vertical depths of 1,027 and 1,576 meters, in the GH-10 and GH-20 wells, respectively. The temperatures decline rapidly to the east and west of the one kilometer wide subsurface zone defined by the Oguni boreholes GH-4, GH-10, GH-11, and GH-12 (Garg, *et al.*, 1995).

The Oguni reservoir fluid appears to be a relatively homogenous sodium-chloride brine of moderate salinity with an average chloride concentration of about 1100 mg/l. The reservoir fluid is a single-phase liquid. None of the geothermal boreholes provide any direct evidence of a two-phase zone at depths greater than 300 meters in the Oguni Geothermal Field; however, the presence of boiling at depths less than 300 meters is suggested by the occurrence of warm and boiling steam-heated sulfate and bicarbonate spring waters in the area. The feedzones for all of the Oguni boreholes are deeper than 400 meters.

2.2 Sumikawa Geothermal Field, Honshu, Japan

The Sumikawa Geothermal Field (Figure 1) is located in the Hachimantai volcanic area in northern Honshu, Japan, about 1.5 kilometers to the west of the Ohnuma Geothermal Power Plant. The Sumikawa field is located along the western edge of a north-south oriented regional graben structure which extends many kilometers both north and south of the Sumikawa area. The subsurface geological sequence consists of volcanics, sediments, and crystalline rocks (altered andesite, granodiorite and diorite). The pre-Tertiary basement, which presumably underlies the above sequence, has not yet been reached although the SC-1 well has a total depth of 2,486 meters.

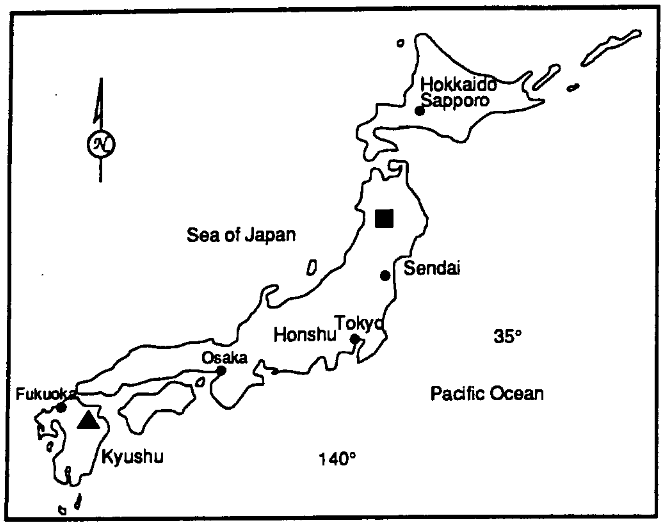

Figure 1. A map of Japan showing locations of the Oguni (dark triangle) and Sumikawa (dark rectangle) Geothermal Fields.

The vertical permeabilities at Sumikawa are small in comparison with horizontal permeabilities and permeability in the field is due primarily to a pervasive network of fractures. Pressure transient tests have been interpreted to imply the presence of two high-transmissivity geothermal aquifers within the altered andesite and the deeper granodiorite formation (Pritchett, *et al.*, 1990; Garg, *et al.*, 1991). The shallower of these two reservoirs in the andesite is usually encountered between 1,000 and 1,800 meters depth, and has been penetrated by several wells. At present, only well SC-1 produces a substantial quantity of hot fluid from the granodiorite formation. Subsurface temperatures are highest to the south and decline to the north and northwest with an average reservoir temperature of about 250°C (Garg and Combs, 1995). The highest temperature thus far measured in the field is 320°C at a total vertical depth of 1,943 meters in well SA-2.

The Sumikawa reservoir fluid is of low salinity (<3,000 ppm) and the noncondensible gas content is also very low, typically <0.1 percent by volume of the produced steam. The geothermal reservoir fluids are mainly of the Na-Cl type with a near neutral pH. A two-phase (water and steam) flow region is present in the southern part of the reservoir system at depth. Since temperatures generally increase to the south in the Sumikawa area, it would appear that the depth to the bottom of the two-phase zone increases to the south. The feedzones for all of the Sumikawa boreholes are deeper than 400 meters.

2.3 Steamboat Hills Geothermal Field, Nevada, U.S.A.

The Steamboat Hills Geothermal Field (Figure 2) is located about 15 km south of Reno, in west-central Nevada, U.S.A. The Steamboat Hills geothermal reservoir is a fracture-controlled resource hosted in granitic rocks (Combs and Goranson, 1995). The oldest rock unit present in the northeast Steamboat Hills, and the geothermal reservoir host, is granodiorite of Mesozoic age. Younger Tertiary sedimentary and volcanic rocks as well as alluvial deposits overlie the granodiorite. Three systems of faulting have been recognized in the Steamboat Hills (van de Kamp, 1991); however, the primary faults controlling fluid circulation in the geothermal reservoir appear to be the northeast trending series of steep normal faults. The deepest borehole was completed in the granodiorite at a depth of 1,219 meters.

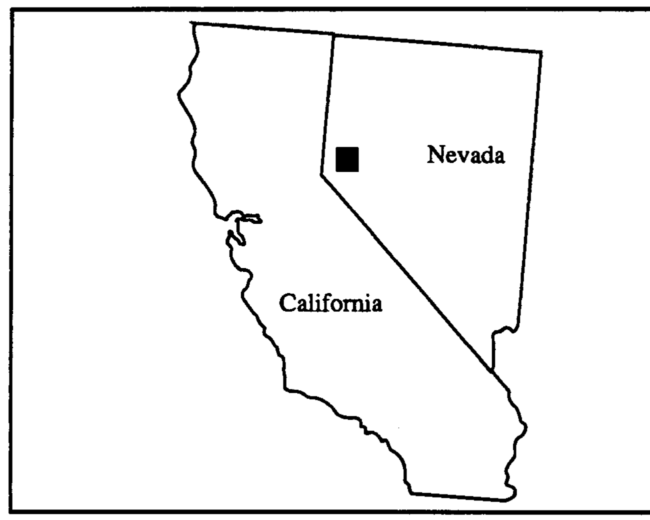

Figure 2. A map of southwestern United States showing location (dark rectangle) of Steamboat Hills Geothermal Field.

The Steamboat Hills is a moderate temperature resource (temperature ~165°C) and covers an area of about 6 km^2, including hot springs and numerous fumaroles associated with siliceous sinter surface deposits. The reservoir fluid is single-phase liquid and has a chlorinity of approximately 800 mg/l. Geothermal fluids are produced from fractured granodiorite at a depth of approximately 300 m. Like the Oguni and Sumikawa Geothermal Fields, the formation permeability at Steamboat Hills is provided by fractures in the host rock. Near vertical, open fractures in the granodiorite control movement of geothermal fluids. The minimum transmissiity is on the order of 1,400 darcy-meters.

3. COMPARISON OF PRODUCTIVITY AND INJECTIVITY INDICES

Production capacity of a geothermal borehole is mainly determined by pressure losses associated with flow (1) in the reservoir rocks, and (2) in the wellbore. Given downhole conditions (mass flow rate, pressure and flowing enthalpy), equations governing mass and energy transport in the wellbore may be solved to yield the wellhead pressure and flowing enthalpy. Two-phase fluid flow in the wellbore (a common condition in geothermal wells) is, at present, not amenable to strict analytical treatment; instead, empirical correlations for flowing gas quality, friction factor, and heat loss must be employed. Utilization of different empirical correlations often yields widely different results. Despite the difficulties associated with the modeling of fluid flow in geothermal wellbores, the available correlations can be used to provide at least a first approximation of the pressure losses in the wellbore.

Ignoring pressure transient effects, the flow resistance (or pressure losses) of the reservoir rocks can be represented by the productivity index (PI); PI is defined as follows:

$$PI = \frac{\dot{M}}{p_i - p_f} \quad ,$$

where

$\dot{M}$ = discharge rate

p_i = static reservoir pressure (at feedzone depth)

p_f = flowing well pressure (at feedzone depth) .

In order to use discharge data from a slim hole to predict the mass output of a large-diameter well, it is necessary to estimate the variation of productivity index with borehole diameter.

Because of the increased importance of frictional and heat losses in small-diameter boreholes, it is often difficult to discharge slim holes. Injection tests can, however, be performed to determine the injectivity index (defined in a manner analogous to the productivity index). If one can establish a relationship between injectivity and productivity indices, then it should be possible to use injection tests on slim holes to estimate the probable discharge characteristics of large-diameter wells.

During the production and injection tests of both slim holes and large-diameter wells at the Steamboat Hills Geothermal Field, no detectable dowhole pressure changes were observed; this indicates that both the injectivity and productivity indices for Steamboat Hills boreholes are extremely large. In other words, the formation permeability is essentially infinite.

Garg *et al.* (1995) have analyzed production and injection data for the Oguni boreholes. The productivity and injectivity indices for the various Oguni boreholes are listed in Table 1. With the exception of two boreholes (HH-2 and GH-15) in the high pressure zone, liquid conditions prevail at the feedzone depth in Oguni boreholes under discharge conditions. Both the productivity and injectivity indices are available for six of the boreholes with liquid feedzones; these data are displayed in Figure 3. It appears from Figure 3 that, to first order, the productivity and injectivity indices for the Oguni boreholes are equal.

Theoretical considerations (Pritchett, 1993 and Hadgu *et al.*, 1994) suggest that the productivity (or injectivity) index should exhibit only a weak dependence on borehole diameter. Somewhat surprisingly, both the productivity and injectivity indices (see *e.g.*, Figure 4) for Oguni boreholes display a strong dependence on borehole diameter. Garg *et al.* (1995) have suggested that the apparent variation of productivity/injectivity indices with borehole diameter may be due to differences in drilling techniques (*i.e.*, core drilling versus rotary drilling). Most of the slim holes were drilled with complete loss of circulation fluid (dilute bentonite based mud). In contrast with slim holes, drilling fluid circulation was maintained for rotary-drilled large diameter wells. It is thus possible that core drilling (at least in the case of Oguni boreholes) caused greater formation plugging than that resulting from rotary drilling.

The productivity and injectivity indices for thirteen boreholes located within the permeable zone at the Sumikawa Geothermal Field are listed in Table 2. The injectivity indices for the

Table 1. Productivity/Injectivity Indices of Oguni boreholes. Adapted from Garg *et al.* (1995).

Borehole Name	Final Diameter (mm)	Productivity Index (kg/s-bar)	Injectivity Index (kg/s-bar)
A. Low-Pressure Reservoir			
GH-3	79	0.53	—
GH-4	76.	1.44	—
GH-5	76.	1.19	—
GH-7	98.	1.05	—
GH-8	78.	1.01	—
GH-10	159.	3.88	3.39
GH-11	216.	5.65	1.53
GH-12	216.	5.77	5.12
GH-17	216.	—	0.46
GH-20	216.	15.2	7.82
GH-21	216.	—	12.1
IH-1	159.	—	0.84
IH-2	216.	11.9	33.
N2-KW-1	76.	—	2.11
N2-KW-2	76.	—	0.86
B. High-Pressure Reservoir			
GH-6	76.	5.02	—
GH-9	78.	—	0.08
GH-15	216.	0.25*	1.75
GH-19	216.	—	25.7
HH-2	76.	0.03*	—
N2-KW-3	76.	3.85	5.85

**In situ* boiling

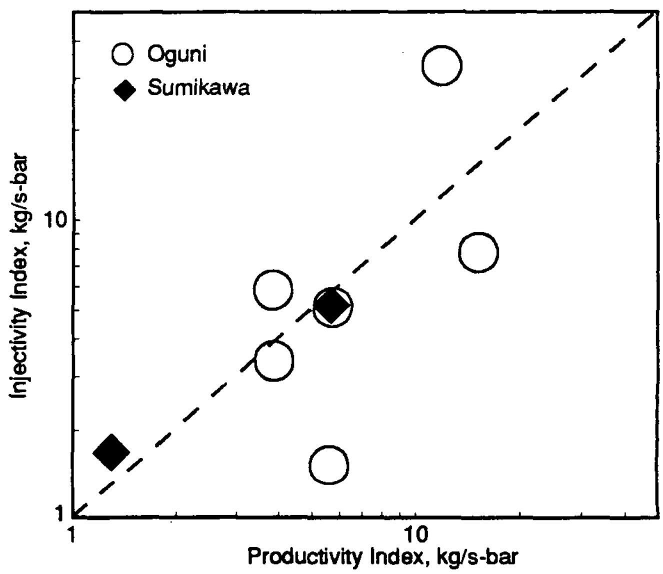

Figure 3. Productivity Index versus Injectivity Index for Oguni and Sumikawa boreholes with liquid feeds.

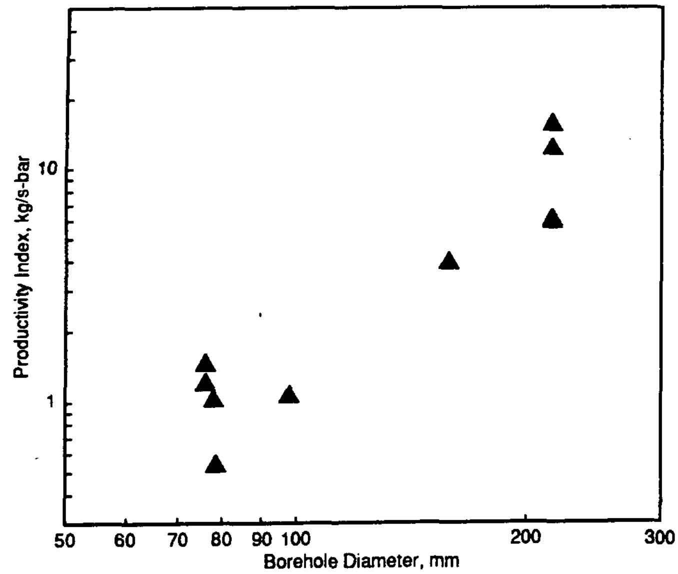

Figure 4. Productivity Index versus diameter for low-pressure reservoir Oguni boreholes.

Table 2. Productivity/Injectivity Indices of Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Productivity Index (kg/s-bar)	Injectivity Index (kg/s-bar)
N60-KY-1	101	—	0.012
S-1	143	0.86*	—
S-2(i)	101	0.027*	0.76
S-2	101	1.3	1.7
S-3	101	—	1.4
S-4	159	0.94*	1.4
SA-1	216	0.16*	1.5
SA-2	216	—	1.5
SA-4	216	0.11*	0.94
SB-1	216	—	2.0
SB-2	216	—	1.6
SB-3	216	—	1.5
SC-1	216	5.7	5.2
SD-1	216	0.51*	0.78

(i): intermediate depth *: *In situ* boiling

Sumikawa boreholes do not depend in any systematic manner on the borehole diameter. Garg and Combs (1995) suggest that the difference between the Oguni and Sumikawa results is due to the differences in drilling conditions at the two fields. As noted earlier, most of the slim holes at Oguni were drilled with a complete loss of circulation. In the case of Sumikawa slim holes, drilling fluid circulation was maintained.

Liquid conditions prevailed at the feedzone depth during discharge testing of Sumikawa boreholes S-2 (completed hole) and SC-1; the productivity and injectivity indices for these boreholes are more or less the same (see Table 2; Figure 3). Production from other Sumikawa boreholes is accompanied by *in situ* boiling. Low formation permeability and high formation temperatures (250°C < T < 320°C) are responsible for *in situ* boiling on discharge. The formation transmissivity for two-phase flow is always smaller than that for liquid flow. For Sumikawa boreholes with *in situ* boiling (Table 2), the productivity index is, as expected, smaller than the corresponding injectivity index.

4. VARIATION OF DISCHARGE RATE WITH BOREHOLE DIAMETER

At the Oguni and Steamboat Hills Geothermal Fields, the formation permeability (and productivity indices) is sufficiently large such that the pressure losses in the reservoir are insignificant compared to pressure losses in the borehole. The discharge behavior of Oguni and Steamboat Hills boreholes is principally determined by pipe friction and heat losses in the wellbore. This situation is quite different from that prevailing at the Sumikawa Geothermal Field. At Sumikawa, pressure losses in the formation constitute the bulk of pressure losses in boreholes for which discharge is accompanied by *in situ* boiling.

Pritchett (1993) carried out numerical simulations to investigate the fluid carrying capacity of boreholes of varying sizes. In his work, Pritchett (1993) assumed (1) pressure losses in the formation are negligible and (2) borehole produces from a liquid feedzone. Based on these numerical simulations, Pritchett (1993) found that the maximum discharge rate M_{max} increases at a rate somewhat greater than the square of borehole diameter.

$$M_{max} = M_o\left(\frac{d}{d_o}\right)^{2+n} \quad ,n > 0$$

where M_{max} (M_o) is the discharge rate of a borehole with internal diameter $d(d_o)$. In general, the value of n may be expected to vary with feedzone conditions (depth, pressure, enthalpy, gas content) and well completion (uniform or non-uniform internal diameter). For the conditions assumed by Pritchett (feedzone depth = 1500 m, pressure = 80 bars, single phase liquid at 250°C, uniform borehole diameter) n is approximately equal to 0.56. Clearly, the conditions assumed in Pritchett's work do not hold for most of the Sumikawa boreholes for which production is accompanied by *in situ* boiling.

The "area-scaled discharge rate" M^* is defined as follows:

$$M^* = M_o\left(\frac{d}{d_o}\right)^2 \quad .$$

The "area scaled" and "scaled maximum ($n = 0.56$)" discharge rates for the slim holes are compared with measured discharge rates from large-diameter wells in Tables 3–5.

The average discharge rate (311 tons/hour) for the Oguni low-pressure zone large diameter wells is bracketed by the averaged "area scaled" (194 tons/hour) and averaged "scaled maximum" (338 tons/hour) discharge rates. In addition, using the slim hole data, the predicted M^* and M_{max} for GH-10 (159 mm diameter) are 105 tons/hour and 155 tons/hour, respectively. By comparison, the measured discharge rate for GH-10 is 164 tons/hour. Thus, for the Oguni boreholes (liquid feeds), the "scaled maximum discharge rate" provides a reasonable prediction of the maximum discharge rate of large-diameter geothermal wells based on discharge data from slim holes.

At the Steamboat Hills Geothermal Field, large-diameter production wells were drilled within a few meters of the corresponding slim holes (TH-1/PW3-3, TH-2/PW2-1, TH-3/PW2-5, SNLG87-29/HA-4). Large-diameter production

Table 3. Measured and predicted discharge rates for Oguni boreholes. Adapted from Garg *et al.* (1995).

Borehole Name	Final Diameter (mm)	Measured Discharge (tons/hr)	M^* Area Scaled Discharge† (tons/hr)	M_{max} Scaled Maximum Discharge†† (tons/hr)
A. Low-Pressure Reservoir				
GH-3	79	20	151	266
GH-4	76	27	218	391
GH-5	76	22	178	319
GH-7	98	30	146	227
GH-8	78	36	276	488
Average (GH-3 to GH-8)			194	338
GH-10	159	164		
GH-11	216	279		
GH-12	216	279		
GH-20	216	369		
IH-2	216	316		
Average (GH-11 to IH-2)		311		
B. High-Pressure Reservoir				
GH-6	76	24	194	348
GH-15	216	36*		
HH-2	76	5*	40	72
N2-KW-3	76	28	226	406

† Area-Scaled Discharge Rate = Measured Discharge Rate × $(216/\text{well dia. in mm})^2$

†† Scaled Maximum Discharge Rate = Measured Discharge Rate × $(216/\text{well dia. in mm})^{2.56}$

* Two-Phase Flow

Table 4. Measured and predicted discharge rates for Steamboat Hills boreholes.

Borehole Name	Final Diameter (mm)	Measured Discharge (tons/hr)	M^* Area Scaled Discharge† (tons/hr)	M_{max} Scaled Maximum Discharge†† (tons/hr)
TH-1	70	11.6	132	260
TH-2	70	12.6	143	283
TH-3	70	18.6	211	418
SNLG87-29	99	25.0	142	231
Average (TH-1 to SNLG87-29)			157	298
PW3-3	236*	216		
PW2-1	236*	237		
PW2-5	236*	379		
HA-4	236*	194		
Average		257		

† Area-Scaled Discharge Rate = Measured Discharge Rate × $(236/\text{well dia. in mm})^2$

†† Scaled Maximum Discharge Rate = Measured Discharge Rate × $(236/\text{well dia. in mm})^{2.56}$

* See text

wells (nominal inside diameter = 311 mm) were tested with drill pipe (diameter = 11.4 cm) set at 183 m. Drill collars (diameter = 20.3 cm) were present in the wellbore from ~134 m to ~183 m. The presence of drill pipe/drill collars reduces the equivalent wellbore diameter to 289 mm and 236 mm over the depth intervals 0–134 m and 134–183 m, respectively. All the large-diameter wells were flowed through a surface piping (25-cm diameter tubing for PW series wells; 20-cm diameter tubing for HA-4 well). The use of surface tubing adds a back-pressure to the wellhead, thereby reducing the maximum flow rate for the well. Taking into account data limitations, the measured discharge rates for large-diameter wells at Steamboat Hills are adequately approximated by the "scaled maximum discharge rates" computed from slim hole test data.

Table 5. Measured and predicted discharge rates for Sumikawa boreholes. Adapted from Garg and Combs (1995).

Borehole Name	Final Diameter (mm)	Measured Discharge Rate (tons/hr)	Area Scaled Discharge* (tons/hr)	Scaled Maximum Discharge** (tons/hr)
A. Boreholes with liquid feeds and no *in situ* boiling				
52-E-SM-2	79	27	202	355
S-2	101	52	238	364
S-3	101	16	73	112
SB-1	216	105		
SC-1	216	490		
B. Boreholes with limited *in situ* boiling				
S-4	159	180	332	394
SD-1	216	100		
C. Boreholes with extensive *in situ* boiling				
52E-SM-2(i)	101	5.1	23	36
S-2(i)	101	4.1	19	29
S-1	143	35	80	101
SA-1	216	62		
SA-2	216	28		
SA-4	216	30		

* Area-Scaled Discharge Rate = Measured Discharge Rate × $(216/\text{well dia. in mm})^2$

** Scaled Maximum Discharge Rate = Measured Discharge Rate × $(216/\text{well dia. in mm})^{2.56}$

(i) Intermediate depth

The discharge rates for Sumikawa wells SB-1 (liquid feed) and SD-1 are approximately equal to the scaled maximum discharge rate for slim hole S-3. The scaled maximum discharge rates for slim holes S-2 and 52E-SM-2 (liquid feeds) provide an adequate prediction for discharge from well S-4. The measured discharge rate for well SC-1, however, exceeds the scaled maximum discharge rate for slim holes S-2 and 52E-SM-2 by about 25 percent. The maximum discharge (scaled to a nominal 216-mm diameter) rates for Sumikawa boreholes with little or no *in situ* boiling range from 100 tons/hour (well SD-1) to 490 tons/hour (well SC-1). The comparable range for Oguni wells extends from 227 ton/hour (slim hole GH-7) to 488 ton/hour (slim hole GH-8). Although the Sumikawa boreholes display considerably more variability in discharge rates than the Oguni boreholes, the "scaled-maximum discharge rate" provides a reasonable first prediction of the discharge performance of large-diameter geothermal wells at Sumikawa (with little or no *in situ* boiling).

The measured maximum discharge rates for Sumikawa boreholes with extensive *in situ* boiling are substantially lower than for boreholes with liquid feedzones. The average scaled maximum discharge rate for slim holes 52E-SM-2(i), S-2(i), and S-1 is 55 tons/hour. By comparison, the average measured discharge rate for production wells SA-1, SA-2 and SA-4 is 40 tons/hour. The latter value for discharge rate (40 tons/hour) is not too different from that for Oguni well GH-15 (36 tons/hour). Oguni slim hole HH-2 has a scaled maximum discharge rate of 72 tons/hour. The available data from Oguni and Sumikawa boreholes with extensive *in situ* boiling suggest that the scaling rule ($n = 0.56$) derived for boreholes with liquid feeds is not applicable to boreholes with two-phase feeds, and therefore, additional theoretical work is needed.

5. CONCLUSIONS

Discharge and injection data from slim holes and large-diameter wells at three geothermal fields (Oguni, Japan; Sumikawa, Japan; Steamboat Hills, USA) have been examined to establish relationships (1) between discharge capacity of slim holes and large-diameter wells, (2) between injectivity and productivity indices of slim holes and large-diameter wells, and (3) between productivity/injectivity indices and borehole diameter. For boreholes producing from an all-liquid feedzone, the "scaled maximum discharge rate" (Pritchett, 1993) provides a reasonable prediction of production potential of large-diameter geothermal wells based on discharge data from slim holes. Data from boreholes (four slim holes, four large-diameter wells) which produce from a two-phase zone suggest that the "scaled maximum discharge rate" yields too high a prediction for the discharge rate of large-diameter wells. Additional data and theoretical work are needed to draw firm conclusions regarding the scalability of discharge data for boreholes with two-phase feedzones.

Available productivity and injectivity indices for Oguni and Sumikawa boreholes with liquid feeds indicate that to first order the indices are equal. These data imply that for fractured geothermal reservoirs, the inability to discharge slim holes does not necessarily render the use of slim holes to predict the behavior of large-diameter wells impractical. In the absence of discharge testing and the resultant productivity index, the injectivity index may be used to characterize the flow resistance of reservoir rocks, and, therefore provide a prediction for the production rate of large-diameter geothermal wells.

As far as the relationship between productivity/injectivity indices and borehole diameter is concerned, the data from Sumikawa and Oguni Geothermal Fields displays contradictory trends. The injectivity indices from Sumikawa boreholes show no systematic variation with borehole diameter. On the other hand, both the productivity and injectivity indices for the Oguni boreholes display a strong dependence on borehole diameter. Garg *et al.* (1995) have suggested that enhanced formation plugging in slim holes is responsible for the variation of productivity/injectivity indices with diameter at Oguni; apparently, such formation plugging is not a factor at Sumikawa. Data from additional geothermal fields are needed to determine if enhanced formation plugging in boreholes drilled with coring rigs is an isolated or a pervasive phenomenon.

In summary, the analyses of discharge and injection data discussed above provide a preliminary validation of the premise that it should be possible to forecast the performance of large-diameter wells using discharge and injection data from slim holes. Additional data and theoretical work are required to resolve several issues. Work is continuing on the analysis of production and injection data from slim holes and large-diameter production wells in other geothermal fields. The results of these analyses will be reported in future publications.

6. ACKNOWLEDGMENTS

We express our sincere appreciation to the Electric Power Development Company, Tokyo, Japan (EPDC), the Mitsubishi Materials Corporation, Tokyo, Japan (MMC), and Far West Capital Inc., U.S.A. for permission to use their unpublished proprietary data in this study. This work was supported under contracts AG-4388 and AK-0472 from Sandia National Laboratories.

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