INJECTION PERFORMANCE IN THE BULALO GEOTHERMAL FIELD
MAKILING-BANAHAO AREA, PHILIPPINES

BY

PHILIP H. MESSER
PHILIPPINE GEOTHERMAL, INC.
MANILA, PHILIPPINES

INTRODUCTION

The Bulalo Field is located within the Makiling-Banahao geothermal prospect approximately sixty kilometers southeast of Manila on the main island of Luzon in the Philippines. This hot brine resource is being explored and developed by Philippine Geothermal Incorporated (PGI), a subsidiary of the Union Oil Company of California. During the past five years, forty-two wells have been drilled and completed into the Bulalo heat anomaly. Commercial production was initiated in late April, 1979 to supply steam for the operation of the first generating plant composed of two 55MW units. Field expansion continues for the installation of an additional plant of similar capacity.

Commercial production to date has been primarily limited to ten wells and brine for disposal has been injected into four wells, as depicted in Figure 1. These four injectors are currently deemed as temporary disposal wells which will handle the brine injection requirements until the permanent system is in operation.

COMPLETION CHARACTERISTICS AND INJECTION CONDITIONS

Four peripheral field completions, Bulalo Nos. 2, 4, 5 and 18, have been temporarily converted into brine disposal wells. The location of these injectors within the field is shown in Figure 1. The Bulalo No. 2 well was converted into an injector early in the project life to dispose of the produced brine from well testing. Nearly six billion pounds of produced brine had been injected into the well at 130±°F prior to the start of commercial operation. The produced fluid had been flashed to atmosphere, collected in storage ponds and pumped into the injection well for disposal. The wellhead injection capacity of the Bulalo No. 2 injector at the start of commercial operation is shown in Table 1.

Bulalo No. 5 was not considered an economic producer and was converted into an injection well. Because of its location, the well was not utilized as an injector until commercial injection pumps were available. Both Bulalo No. 2 and No. 5 did not have sufficient injection capacity to dispose of the surplus brine from Plant 1 operation. Two production wells, Bulalo No. 4 and No. 18 were also temporarily converted into injectors to provide the additional interim brine disposal capability. The wellhead injection capacities of the Bulalo Nos. 4, 5 and 18 injectors are shown in Table 1.

Each of the four temporary injection wells is completed in a fractured andesite formation. The completions are composed of a 7" perforated liner suspended in a 9-5/8" cemented casing. Injection profile surveys have shown, in general, that the brine exits the wellbores at intervals corresponding to the zones of major lost circulation that were incurred during drilling. Brine injection intervals in these wells range from 2200 to greater than 6500 feet.

Chemical analyses of the produced brine define a reservoir brine characterized by 2330 ppm chlorides, 16 ppm calcium, 385 ppm potassium, and 615 ppm silica with an average pH of 6.6. The residual brine from the separator is pumped into the injection wells for disposal. Sufficient pressure is maintained to avoid further flashing of the disposal brine after separation. The brine is injected at 325±°F.

INJECTION PERFORMANCE DURING COMMERCIAL OPERATION

The period of commercial operation from May to August of this year was characterized by intermittent production and injection conditions varied greatly. Only the Bulalo No. 2 and No. 5 injectors were utilized during this early operating period, and the wellhead injection capacities of both wells were reduced, as depicted in Figure 2. Pressure falloff surveys defined a reduction in flow capacity; however, no significant change in skin factor was evident. This loss in disposal capacity has not been restored to date. The current wellhead injection capacity and cumulative brine injection are listed in Table 1.

During August of this year, commercial operation became more stable and power generation increased. The brine disposal rates required the addition of the Bulalo No. 4 and No. 18 temporary injectors. Nearly two billion pounds of concentrated brine have been injected into these two wells with no loss of wellhead injection capacity, as shown in Table 1. Similarly, the rate of reduction in the disposal capacity of the Bulalo No. 2 and No. 5 injectors has decreased during this more recent operating period, as shown in Figure 2. The current injection performance data for the Bulalo Nos. 2, 4, 5 and 18 wells are shown in Figure 3. Continuous injection of this high temperature brine is currently felt to be the most suitable means of minimizing injectivity impairment in the Bulalo field.

INJECTION PERFORMANCE PREDICTION AT THE WELLHEAD

The injection data shown in Figure 3 define the wellhead injection characteristics of each of the four temporary brine disposal wells. In addition, the performance curve from saturation pressure to maximum wellhead pressure for each injector shown in the figure has been predicted from reservoir and fluid behavior definition.

A straightforward equation for predicting wellhead injection pressure for a given brine injection rate has been developed. The calculation technique includes the pressure effects caused by the reservoir behavior, the weight of the liquid column and frictional losses encountered in the wellbore. This injection performance equation, as programmed on an HP 67/97 calculator, is as follows:

$$P_s = \frac{0.604q\mu}{\rho kh}\left[\mathrm{Ln}\ (r_e/r_w) - 0.75 + S\right] + P - \frac{L\rho}{144} + \frac{f\nu^2 L\rho}{288g_cD}$$

Where:

P_s	=	stable wellhead pressure, psig
q	=	injection rate, lbs/hr
μ	=	viscosity, cp
S	=	skin factor
kh	=	flow capacity, Darcy-feet
r_e	=	external radius, feet
r_w	=	wellbore radius, feet
P	=	reservoir pressure at datum depth, psig
L	=	datum depth, feet
ρ	=	density of injected brine, lb/cu. ft.
f	=	Moody friction factor
ν	=	brine velocity in wellbore, ft/sec.
D	=	internal diameter of wellbore, feet
g_c	=	conversion factor, 32.2

CONCLUSION

The operating experience that is being gained from the temporary injection system will be valuable in the long-term management of brine disposal in the Bulalo geothermal field. Intermittent injection conditions appear to have caused a loss in the wellhead injectivities of the Bulalo No. 2 and No. 5 wells; whereas continuous injection has led to no major loss in injectivity to date in any of the injectors. Currently, the continuous injection at this high temperature brine condition is felt to be the most suitable means of minimizing injectivity impairment.

REFERENCE:

1. Messer, P.H. and P.F. de las Alas: "The Bulalo Geothermal Reservoir, Makiling-Banahao Area, Philippines," Fourth Workshop on Geothermal Engineering, Stanford University, December 13-15, 1978.

FIGURE 1

THE BULALO GEOTHERMAL FIELD COMPLETION SCHEMATIC

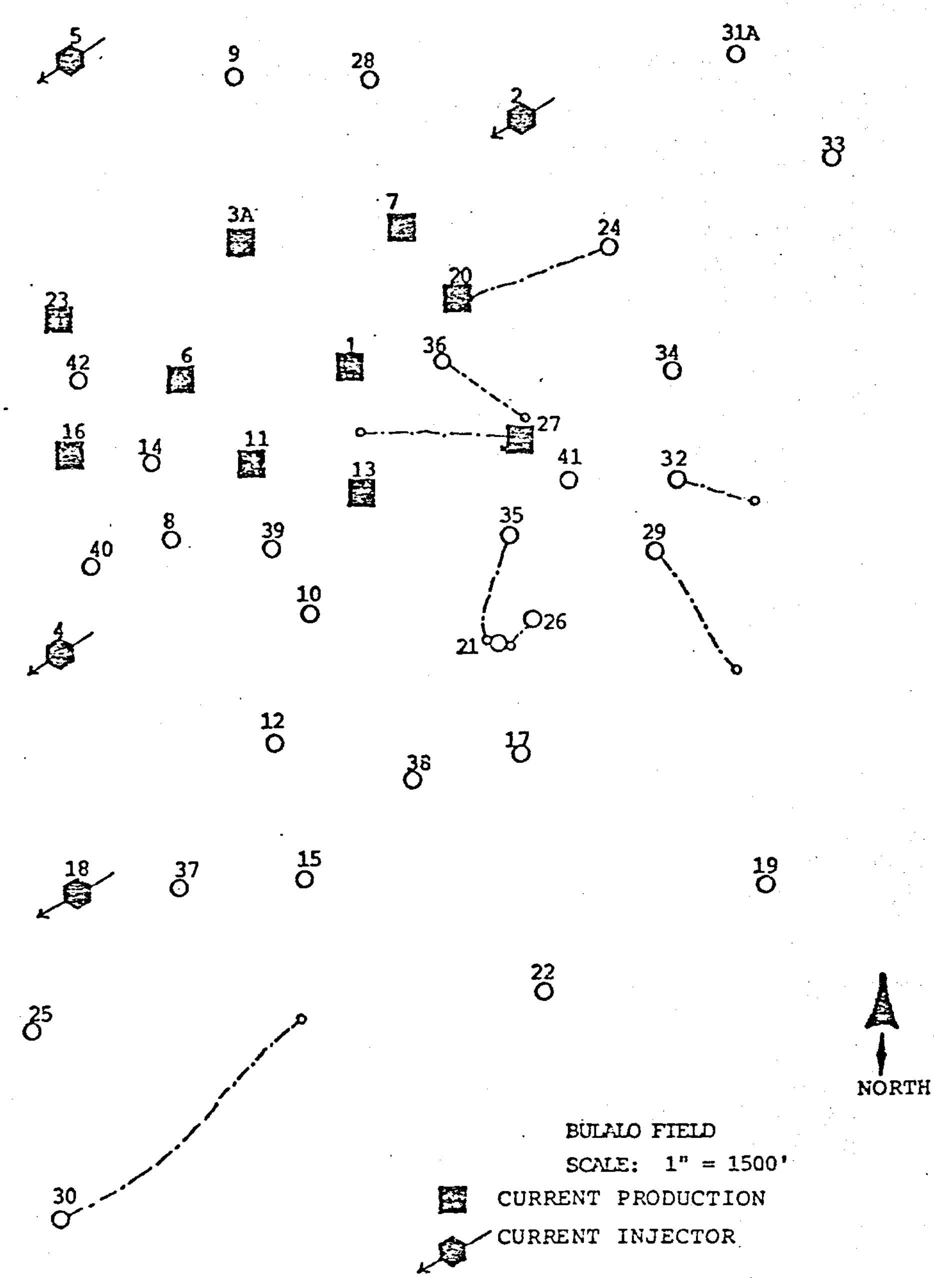

FIGURE 2

MAXIMUM INJECTION RATE VS. CUMULATIVE INJECTION DURING COMMERCIAL OPERATION

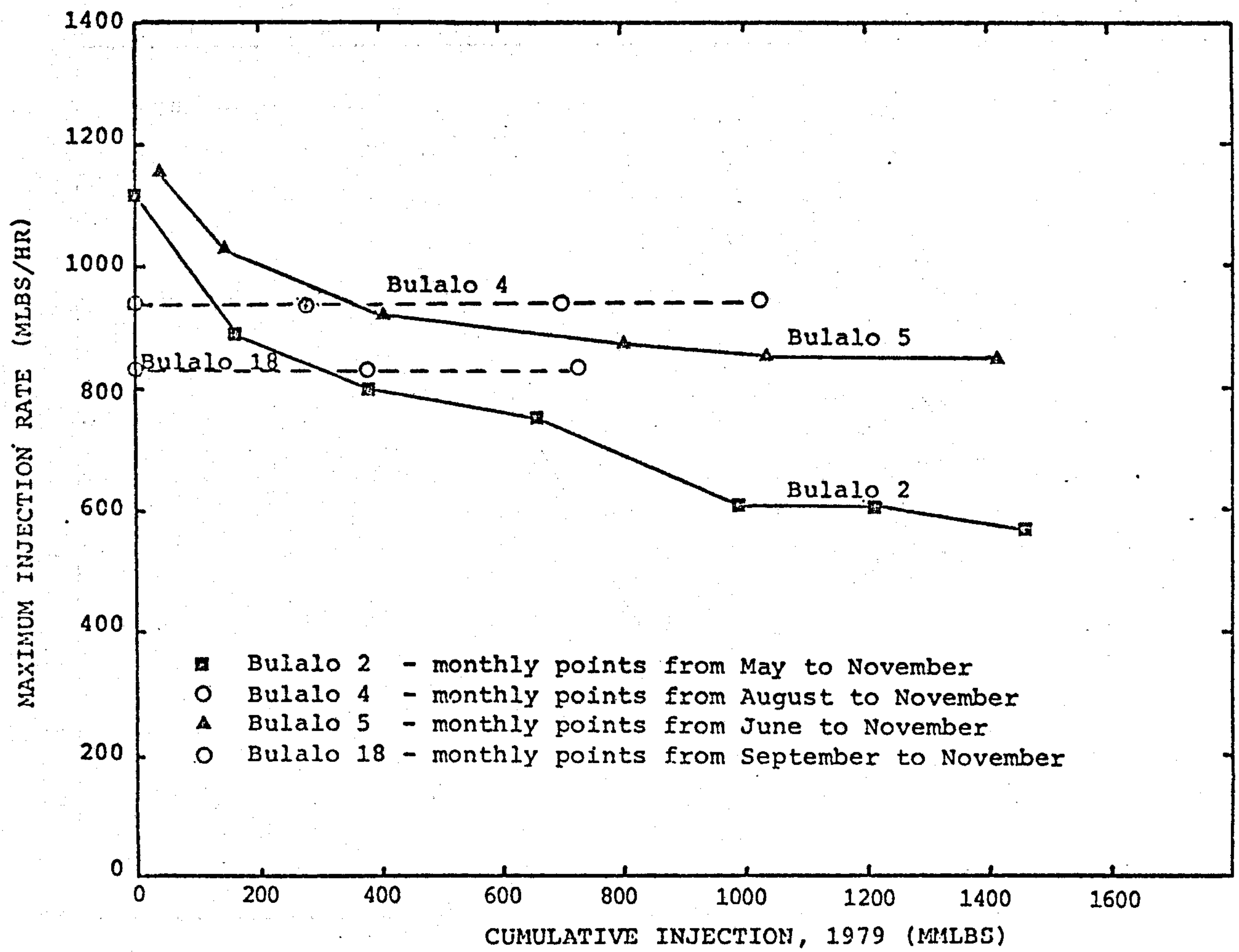

FIGURE 3

BULALO INJECTION PERFORMANCE

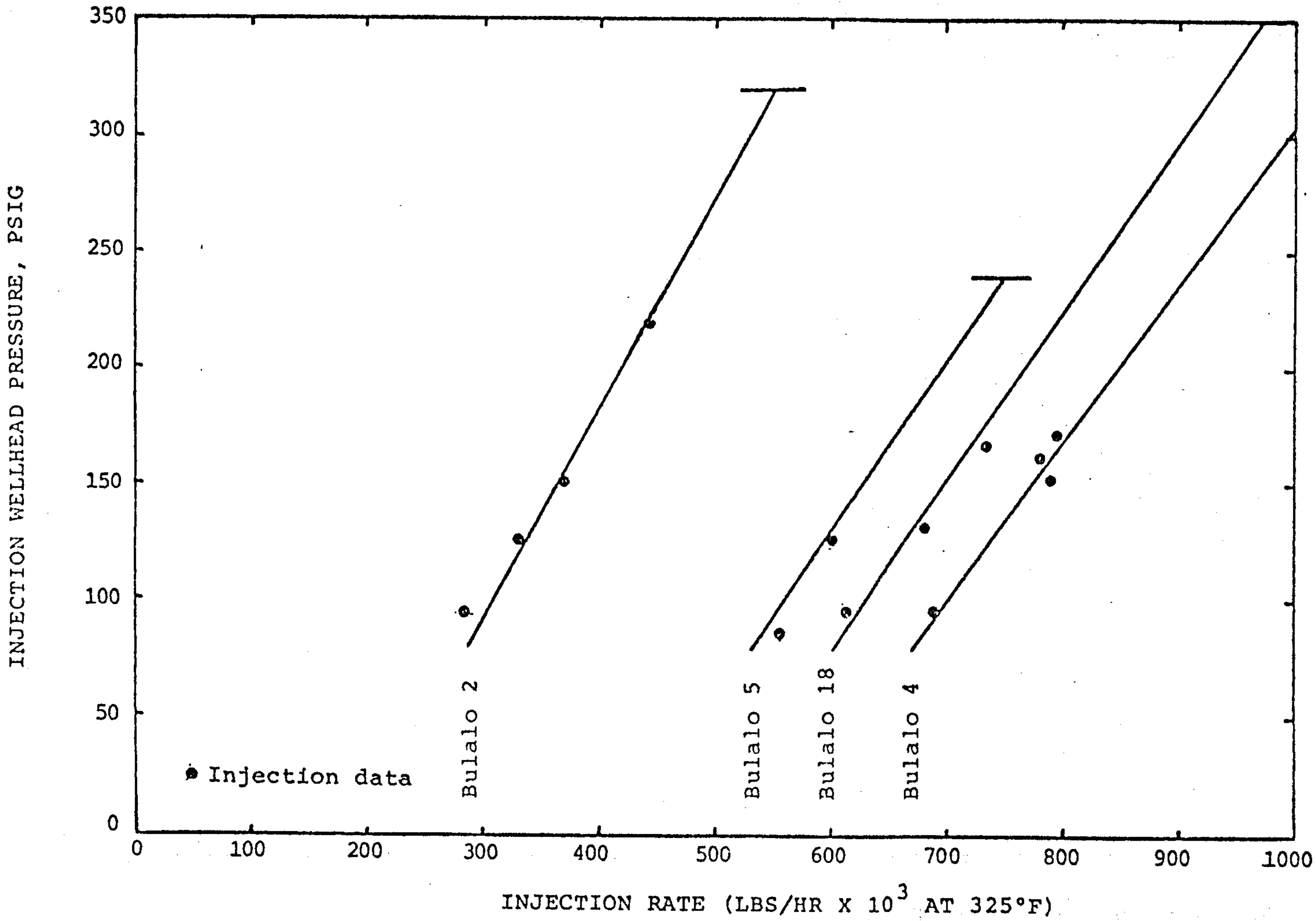

TABLE I

BULALO WELLHEAD INJECTION CAPACITY
DURING COMMERCIAL OPERATION

WELL NO.	MAXIMUM WELLHEAD PRESSURE, PSIG	INITIAL INJECTION RATE LBS/HR	CURRENT INJECTION RATE, LBS/HR	CUMULATIVE INJECTION SINCE COMMERCIAL OPERATION MMLBS
Bulalo 2	320	1,120,000	605,000	1471.9
Bulalo 4	350	940,000	940,000	1020.5
Bulalo 5	240	1,160,000	850,000	1406.0
Bulalo 18	350	830,000	830,000	726.4