RESERVOIR EVALUATION AT THE EAST BRAWLEY (CALIFORNIA) RESOURCE

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Abstract

The East Brawley Geothermal system is a water-dominated, hypersaline resource. Drilling, geology and flow-test data from five wells show that production is dominated by fractures associated with faults and/or igneous intrusives. Resource temperatures of 400 ^{o}F and 500 ^{o}F are obtained at depths below 7,000 feet and 10,500 feet, respectively. Short-term flow tests yielded mass flow rates of 125-515 klb/hr at 100-585 psig wellhead pressures (WHP). Wellbore simulation predicts maximum capacity of 1200 klb/hr at 300 psig WHP with openhole completion and reduced skin damage. Additional flow testing, and exploratory drilling are needed to confirm reservoir extent and conditions.

1.0 INTRODUCTION

The East Brawley geothermal field is located in the east-central Imperial Valley of southern California, approximately 16 miles northeast of El Centro, CA (Fig. 1). There are three producing geothermal fields in the Valley: 1) Salton Sea with **244** MWe, 2) East Mesa with 102 MWe; and **3)** Heber with 92 MWe. East Brawley is designated as a known geothermal resource area (KGRA) and the evaluation in this report is based on limited available data of eight wells drilled in the area.

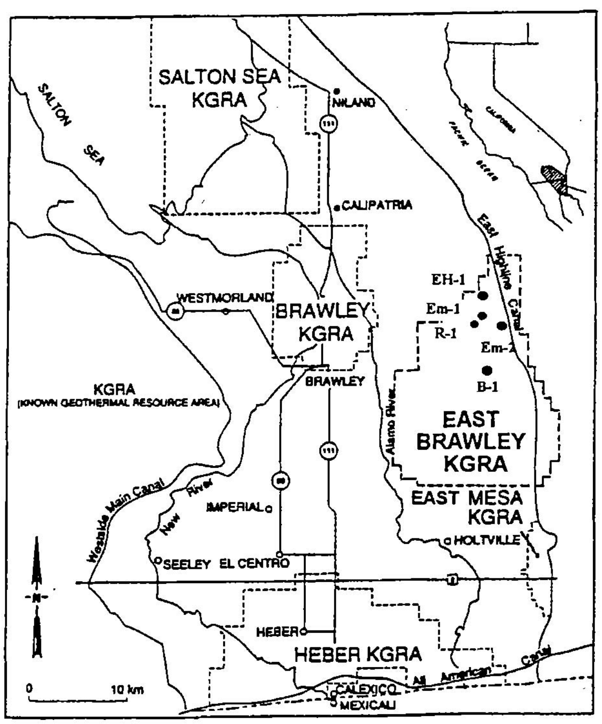


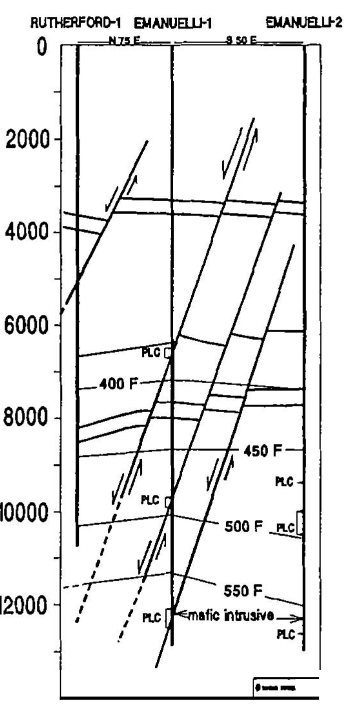
Fig. 1 Location Map of Imperial Valley Geothermal Areas

2.0 GEOLOGY OF THE EAST BRAWLEY FIELD

East Brawley is located in a physiographic province known as the Salton Trough. The Trough is a low-lying depression bounded on the southwest side by the Peninsular ranges and on the northeast side by the Chocolate Mountains. It is a landward extension of the Gulf of California which has been filled with Pliocene to Holocene age alluvial sediments derived from the Colorado River. The Trough is an active continental rift zone in the transition from divergent tectonics of the East Pacific Rise to strike-slip tectonics of the San Andreas Fault system (Elders, 1979). Northwest-southeast trending right lateral strike-slip faults control development of the Trough. East Brawley is referred to as a "blind" resource due to lack of surface hydrothermal manifestations. It was discovered as a result of oil and gas exploration, temperature gradient drilling, and geophysical investigations. East Brawley is characterized by high gravity, low resistivity, and high heat flow anomalies (Brooke and Mase, 1981).

The East Brawley stratigraphy is a sequence of lacustrine clay and silt from surface to 3,300 feet in Emanuelli-1 and Emanuelli-2, and 4,000 feet in Borchard-1 to the south. Below the base of the clay are soft to unconsolidated fluvial siltstones, sandstones, and claystones to a depth of 5,200 feet. Induration increases with depth and degree of alteration. Below 12,200 feet, mafic intrusive rocks were drilled in Emanuelli-1 and Emanuelli-2.

Figure 2 is a cross-section from Rutherford-1 to Emanuelli-2. Normal faults and stratigraphy are mapped using seismic data, induction logs, dipmeter logs, and mudlogs. The cross-section illustrates that fracturing, alteration, and partial loss circulation (PLC) zones are related to the three faults drilled in Emanuelli-1. There are no faults mapped in Emanuelli-2 PLC zones due to limited seismic data and lack of dipmeter log. The faults strike N 0° E to N 20° E, and dip 60° W. The stratigraphic vertical separation ranges from 100 to 500 feet. There was no loss circulation encountered in the fault mapped in Rutherford-1.



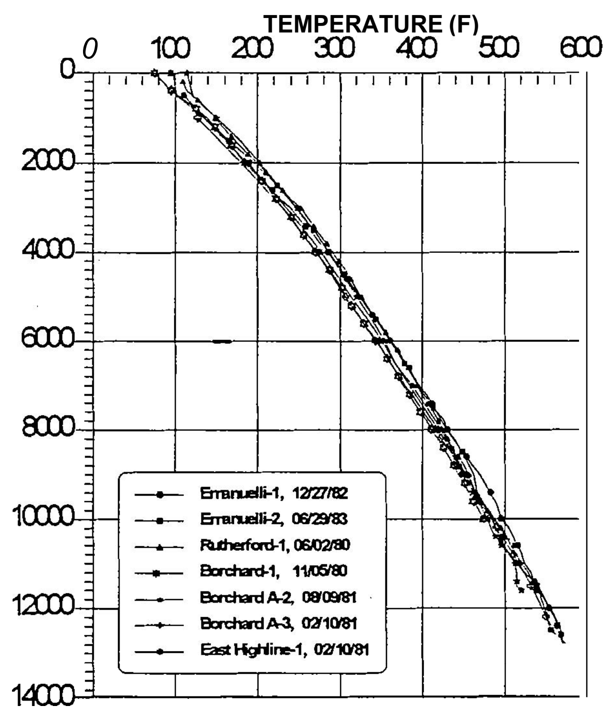


Fig. 3 Static Temperatures with Depth

2.1 TEMPERATURE

Figure 2 indicates the absence of a wide vertical variation in temperature among Emanuelli-1, Emanuelli-2, and Rutherford-1. The plots of static temperature with depth of the East Brawley wells (Fig. 3) show nearly linear gradients of 3.2 to 3.6°F/100 ft which imply relatively--low vertical permeability in the area. Fig. 4 and Fig. 5 show the depths to 450°F and 500°F. The plots show that East Brawley is a deeper resource to exploit compared to the Salton Sea field. The base resource temperature of 400°F is reached at depths below 7,000 feet, and depths to produce fluids at a temperature of 500° F are greater than 10,500 feet. However, production from shallower depths is possible as shown by Rutherford-1 which sustained production after perforating the 9 5/8" casing from 5,805 to 8,576 feet. The maximum temperature measured for the whole field is 586°F at 13,500 feet in Emanuelli-2. Figure 5 shows temperature contours elongated in a N-S direction with a "high" centered near Emanuelli-1. Figure 5 also shows steep gradients to the north and east. The steep gradient from Emanuelli-1 to Emanuelli-2 is probably related to displacement along a fault behveen the two wells (Fig. 2). Temperature gradients decrease to the south towards the Borchard wells.

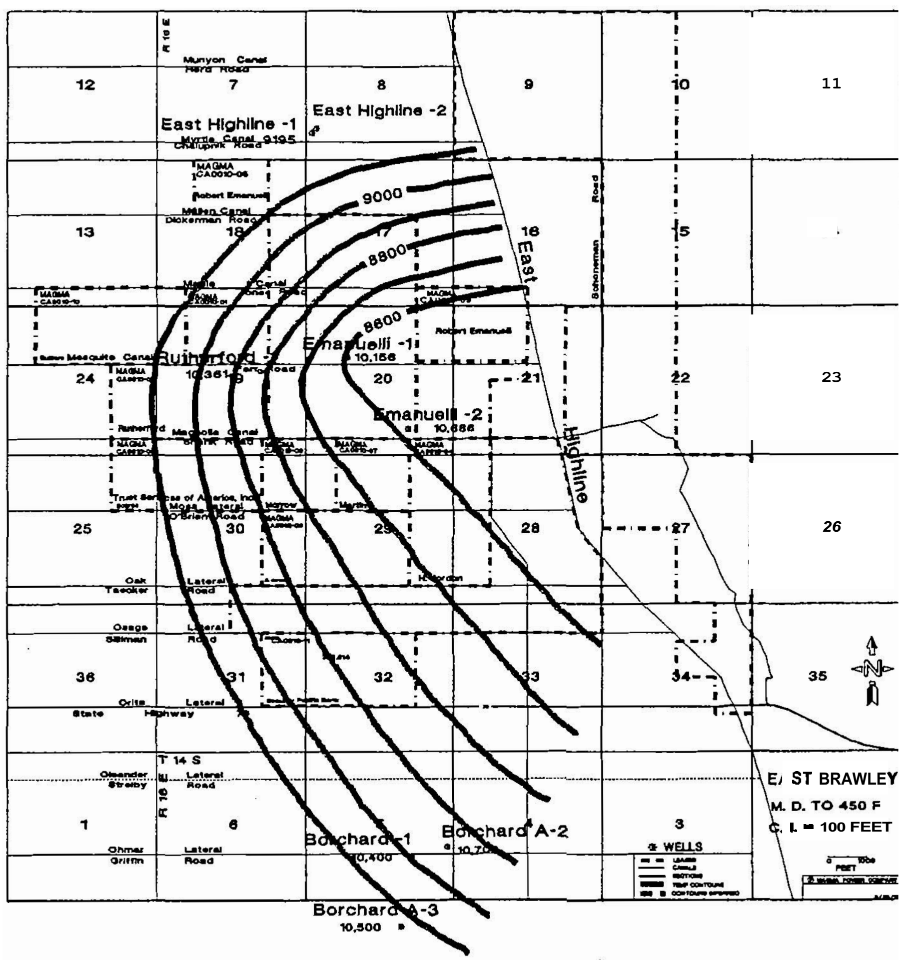


Fig. 4 East Brawley Depth to 450° F Isotherm

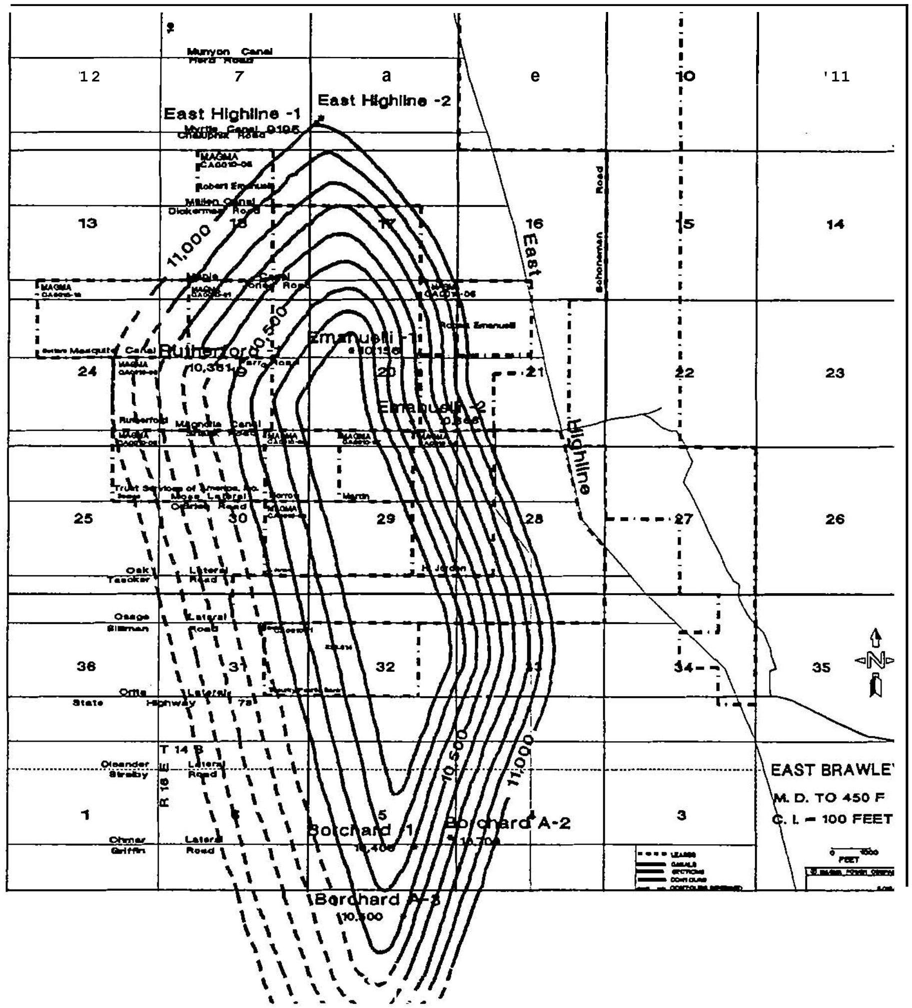


Fig. 5 East Brawley Depth to 500^{0} F Isotherm

3.0 WELLBORE PERFORMANCE AND SIMULATION

All East Brawley deep production wells were completed with a 7" liner perforated at distinct intervals from 8,500 feet to total depth. Permeable zones are due to fractures primarily associated with faulting, and secondly, due to igneous intrusives at bottomhole. Flow tests conducted were limited by time (1-5 days) and/or prematurely terminated due to injection capacities (Potter and Driver, 1983; Potter and Kuo, 1980; Potter and Price, 1981; Potter, *et. al.*, 1982). Total mass flow rates ranged from 125-515 klb/hr at 300-463^{0}F wellhead temperatures and 100-585 psig wellhead pressures. Discharge enthalpy was 320-400 BTU/lb. Fluids produced had salinity of 131,000-139,000 ppm TDS and 1.5-5.8% (weight in total flow) NCG. Well transient analyses showed a wide spread in flow capacity **(kh)** from 600-24000 md-ft. Skin factors ranged from -4 to +12 .

Available production data shown in Fig. 6 indicates three general categories: commercial, poor producer, and sub-commercial. Results of well simulation are shown in Fig. 7, Fig. 8, and Fig. 9.

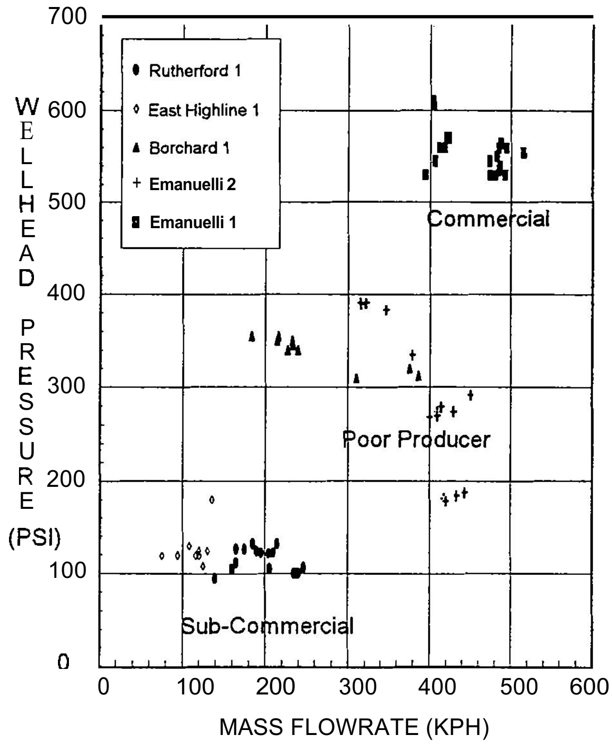


Fig. 6 East Brawley Production Data

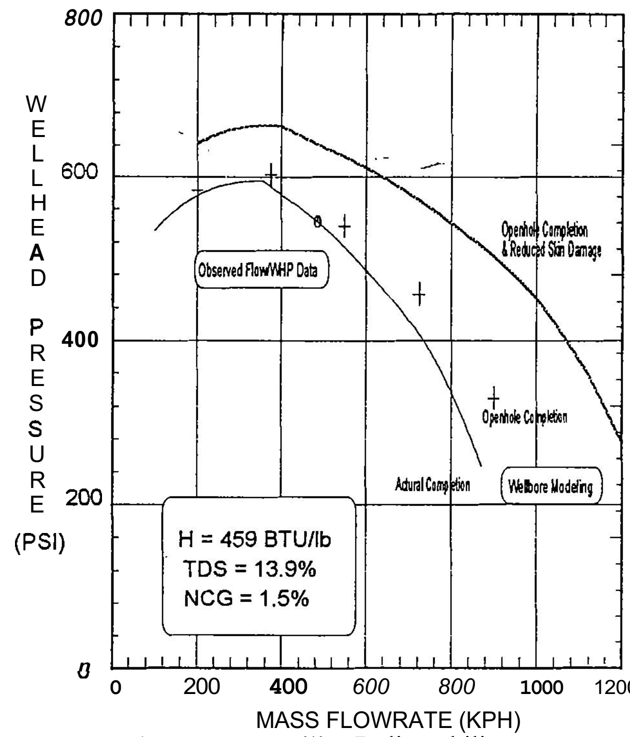


Fig. 7 Emanuelli-1 Deliverability Curve

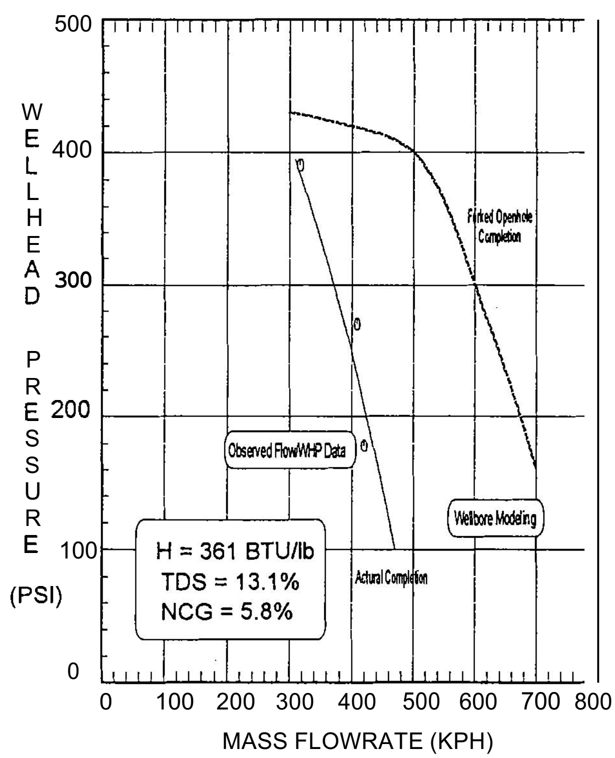


Fig. 8 Emanuelli-2 Deliverability Curve

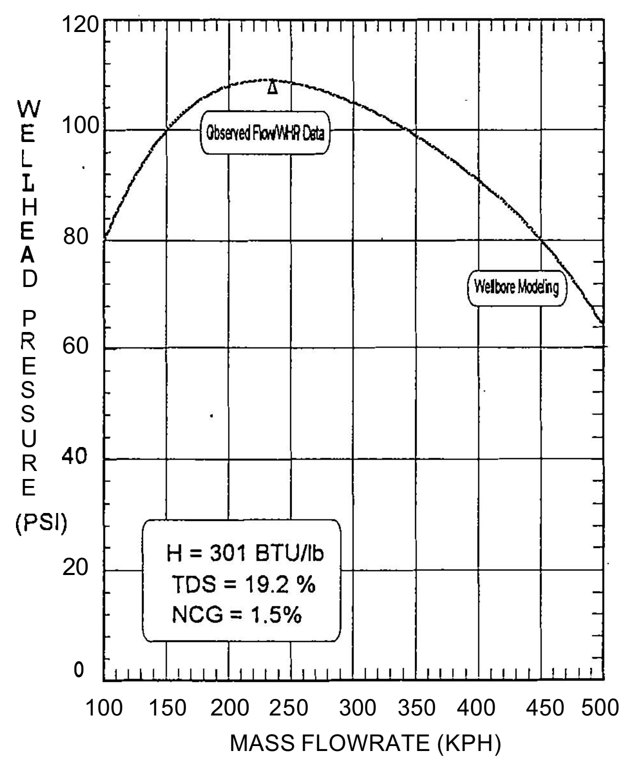


Fig. 9 Rutherford-1 Deliverability Curve

3.1 EMANUELLI-1

Emanuelli-1 is located at the center of the East Brawley anomaly and is the most productive well drilled to date'. This well **is** completed with 9 5/8" casing to 8,492 feet and 7" slotted liner to 12,780 feet. Emanuelli-1 was flow tested for only 28 hours and had not reached maximum flowrates due to injection limitations. Productivity was improving when the test was prematurely terminated. The short-term test produced single-phase fluids of high salinity (139,000 ppm TDS) and moderate scaling potential. Mass flow rates from 403-515 klb/hr at wellhead temperatures of 456-463^{o}F and wellhead pressures of 535-585 psig were obtained. Fluid enthalpy recalculated to reservoir conditions was 475-494 BTU/lb and NCG was 1.5% by weight in total flow. The well was conservatively estimated to have a potential of **5** MWe.

Correlation of the flowtest with survey temperatures indicates that the major feed zone is the bottom portion of the well (12,500-12,700 feet). The permeability for this well is 23,740 md-ft with a skin damage of 12. Wellbore simulation was done using WELLSIM^{TM} to predict deliverability of Emanuelli-1 under different well configurations. With permeability/skin values of Emanuelli-1, a well is espected to have an inflow performance approximately one order of magnitude less than typical Salton Sea wells.

Wellbore modeling results, as shown in Fig. **7,** indicate Emanuelli-1 has a capacity to produce 800 kph at bottomhole temperature of 544^{o} F if the wellhead pressure is lowered to 300 psig. With the high skin damage observed for Emanuelli-1, there is a large potential for improving well performance. The simulation shows that Emanuelli-1 is predicted to produce 1,200 klb/hr at 300 psig WHP and enthalpy of 459 BTU/lb assuming reduced skin damage and larger-diameter (9 5/8") openhole completion.

3.2 EMANUELLI-2

Emanuelli-2 is located 3,900 feet southeast of Emanuelli-1. It was drilled to a total measured depth of 13,510 feet with a **7**" slotted liner from 8,622-13,461 feet. The permeability and enthalpy for this well are significantly lower than those of Emanuelli-1. Well testing showed a flow capacity of 3,400 md-ft. The lower enthalpy can be attributed to 70% of the production coming from an upper zone (8,750-9,500 feet) of relatively lower temperature and enthalpy, and a deep zone (12,300-12,660 feet) of high temperature and enthalpy. The resulting brine had 131,000 ppm TDS, enthalpy of 433 BTU/lb, and 5.8% NCG by weight in total flow. The calculated potential was 4 MWe.

The four-day flow testing (Fig. 6) demonstrated that this well is capable of producing 420 klb/hr at wellhead temperature of 371^{o}F and wellhead pressure of 180 psig. However, wellbore modeling and the observed drawdown of 2,300 psi at 420 klb/hr flowrate signifies flashing at the sandface. This flashing in the formation may esplain the high NCG content of the well.

Wellbore modeling was performed to predict the flow capacity of a well using multiple openhole completions. The result of this modeling is shown in Fig. **8.** The difference between the enthalpy from flow testing and simulation is due to empirical correlations used. Using two **8** 5/8" openhole completions, flow capacity for this well is projected to be 600 klb/hr at 300 psig WHP and enthalpy of 361 BTU/lb. Higher flow can be achieved at lower wellhead pressures but the resultant flashing at the sandface will increase the chance of wellbore/formation plugging.

3.3 RUTHERFORD-1/EAST HIGHLINE-1

Rutherford-1 is located ~3,000 feet west-southwest of Emanuelli-1, while East Highline-1 is located ~8,000 feet north of Emanuelli-1. Both were completed at relatively "shallow" depths (11,000 feet). After initial attempts to flow Rutherford-1, the well was injected with wafer and, later was stimulated with acid displaced with water. Flow rates were sustained only when the 9 5/8" casing was selectively perforated at higher levels (5,805-7,590 feet) in the well. Calculated flow capacity (kh = 845 md-ft) **is** lower **than** Emanuelli-1 (23,740 md-ft) and Emanuelli-2 (3,400 md-ft). Productivity index was similar to that of Emanuelli-2. During the 3-day flow test (Fig. 6), Rutherford-1 had not stabilized but flowed at a maximum rate of 260 klb/hr at a wellhead pressure of 105 psig and wellhead temperature of 345°F. From flow tests, the well has a potential of 1.9-2.5 MWe. Reservoir fluid enthalpy was 390-415 BTU/lb and fluid chemistry data was not stable.

East Highline-1 had a similar flow capacity (kh = 661 md-ft) to Rutherford-1. It flowed at a maximum of 130 klb/hr at wellhead pressure of 130 psig and wellhead temperature of 298°F (Fig. 6). East Highline-2 was not tested although the well attained a maximum temperature of 583° F.

Due to lack of recorded separation pressures for Rutherford-1, the separator pressure reported for East Highline-1 was used to model Rutherford-1. Wellbore modeling results, shown in Fig. 9, indicate that in its actual completion, Rutherford-1 could flow up to 500 klb/hr at low wellhead pressures of 65 psig. The low flow rate is due to the low permeability compared to Emanuelli-1 and Emanuelli-2.

3.4 BORCHARD WELLS

The Borchard wells are located about 3.4 miles south of Emanuelli-1. Of the three Borchard wells, only Borchard-1, drilled to a depth of 13,404 feet, sustained flow. At bottom, Borchard-1 had a static temperature of 571°F; Borchard A-2 had a bottomhole temperature of 533°F at 11,488 feet; and Borchard A-3 had 561°F at 12,468 feet. Borchard-1 had a 7" liner perforated from 11,695-13,315 feet. It was tested for four days and flowed at an average of 272 klb/hr with wellhead pressure of 335 psig and wellhead temperature of 437°F. There were no available chemistry and permeability data.

3.5 WELL SUMMARY

Emanuelli-1, located at the center of the East Brawley anomaly, has demonstrated that commercial rates are possible at East Brawley. Rutherford-1 is espected to be a better producer if deepened to improve permeability and flow capacity. Emanuelli-2 and Rutherford-1, suggest that the area for commercial production wells is within 4,000 feet of Emanuelli-1.

4.0 CONCLUSION

The resource at East Brawley has been evaluated **by** correlating the results of geology, drilling, and flow-testing of five wells. The results show the East Brawley geothermal system is a water-dominated, hypersaline resource. Production is mainly derived from fractures associated with faults and/or igneous intrusives. Resource temperatures of 500° F are obtained at depths below 10,500 feet. Short-term flow testing yielded total mass flow rates of 125-515 klb/hr at 100-585 psig wellhead pressures and 300-463°F wellhead temperatures. Wellbore simulation predicts that with larger-diameter holes and reduced skin damage, maximum capacity of 1200 klb/hr at 300 psig WHP can be obtained.

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