GEOTHERMAL WELLS IN IMPERIAL VALLEY, CALIFORNIA: DESALTING POTENTIALS, HISTORICAL DEVELOPMENT, AND A SELECTED BIBLIOGRAPHY

by

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ABSTRACT

Reclamation, importation, and desalting systems are energy-intensive and energy shortages are at hand. A potentially important source of energy is geothermal brine, a subterranean resource existing in abundance in the Imperial Valley, California which is, in turn, an area in short supply of good quality water. A history of Imperial Valley geothermal well drilling is provided in this paper. Current developments suggest the possibilities of two technological breakthroughs: utilization of 300° to 400° F brines in the world's first binary fluid closed cycle geothermal power plant and the world's first operational geothermal desalting plant.

INTRODUCTION

The likelihood of future water shortages has become a serious concern in many areas. Possible solutions include wastewater reclamation, importation, and desalting of sea or brackish water, but all of these are energy-intensive, and energy shortages are also present. However, a potentially important source of readily available energy is geothermal brine. Technology is rapidly advancing in geothermal energy production and, at the same time, desalting technology has been improving at a pronounced rate. Consequently, geothermal desalting itself is now very promising and may contribute significantly to future water resource development[1, p. 195].

Vapor-dominated ("dry-steam") geothermal systems are being exploited at Larderello, Italy; The Geysers, California; and Matsukawa, Japan. Vapor-dominated systems produce superheated steam, but no water, and hence have been best suited for single-purpose energy production. Hot-water systems, however, are up to twenty times as common as vapor-dominated systems[2, p. 42] and appear to have a considerable potential for dual-purpose power-water developments.

The world's major hot-water geothermal areas are Wairakei and Broadlands in New Zealand; the Yellowstone geyser basins in Wyoming; Cerro Prieto in Mexico; and the Imperial Valley in California[3, p. 12]. Within the Imperial Valley, field research is underway in the areas of heat-exchange technology and geothermal desalting.

In the heat-exchange system (vapor-turbine cycle or "closed" system), hot-brine is pumped up from the geothermal reservoir and the phase-change of water flashing to steam is suppressed. The brine passes through a heat exchanger where it cools while it heats a secondary low-boiling fluid, such as isobutane or freon, which is used to drive a turbogenerator in a closed cycle. The cooled brine is injected into a nearby well and thus helps to maintain the underground reservoir pressures. This vapor-turbine cycle has been named the "Magmamax" power process by Magma Energy, Inc., of Los Angeles[4, p. 166].

The possible importance of geothermal desalting has been stressed by L. J. P. Muffler.

> *"Successful demonstration of the technical feasibility of geothermal self-desalination could greatly enhance the economic position of geothermal resources. Particularly in water-short parts of the world, geothermal energy may be the preferable energy source for desalination, either of the geothermal brine itself or of other saline waters near the geothermal development."*[5, p. 256]

The problem of brine disposal has been an important bottleneck holding back geothermal development in the Imperial Valley. Approximately two pounds of brine are produced for every pound of steam. R. W. Rex, a leader in geothermal exploration and development, has suggested

TABLE 1

GEOTHERMAL WELLS IN IMPERIAL VALLEY, CALIFORNIA

Well	Location/Anomaly	Date Completed (mo/yr)	Depth (feet)	Maximum Temperature (^{o}F)	Operator
P.D. 1	11S/13E/Buttes	6/27	728	244	Pioneer Development
P.D. 2	11S/13E/Buttes	10/27	1263	?	Pioneer Development
P.D. 3	11S/13E/Buttes	2/28	1473	?	Pioneer Development
Sinclair 1	11S/13E/Buttes	2/58	4723	561	Kent Imperial Oil Co.
Sportsman 1	11S/13E/Buttes	3/61	4730	590	O'Neill Geothermal
I.I.D. 1	11S/13E/Buttes	3/62	5232	622	O'Neill Geothermal
Sinclair 3	11S/13E/Buttes	4/63	6921	536	Western Geothermal
I.I.D. 2	11S/13E/Buttes	12/63	5802	626	Shell Development
River Ranch 1	11S/13E/Buttes	1/64	8098	653-800	Earth Energy, Inc.
State of Calif. 1	11S/13E/Buttes	5/64	4838	590	Shell Development
Elmore 1	11S/13E/Buttes	5/64	7118	770	Earth Energy, Inc.
Sinclair 4	11S/13E/Buttes	6/64	5304	428	Western Geothermal
Hudson 1	11S/13E/Buttes	7/64	6114	500	Earth Energy, Inc.
I.I.D. 3	11S/13E/Buttes	3/65	1696	392	Imperial Thermal Products
Magmamax 1	11S/13E/Buttes	1/72	2804	509	MPC/SDGE
Dearborn 1	12S/13E/none	abandoned			MPC/SDGE
Sharp 1	15S/16E/Mesa	abandoned			MPC/SDGE
Woolsey 1	11S/13E/Buttes	3/72	2401	460	MPC/SDGE
Holtz 1	16S/14E/Heber	3/72	?	>320	MPC/SDGE
Holtz 2	16S/14E/Heber	7/72	?	>320	MPC/SDGE
Dunes 1	15S/19E/Dunes	8/72	2007	270	DWR/UCR
Mesa 6-1	16S/17E/Mesa	8/72	8030	392	Bureau of Reclamation
Magmamax 2	11S/13E/Buttes	11/72	4303	532	MPC/SDGE
Magmamax 3	11S/13E/Buttes	11/72	4003	610	MPC/SDGE
Nowlin Partnership 1	16S/14E/Heber	11/72	5030	320	Chevron Oil Co.
Magmamax 4	11S/13E/Buttes	12/72	2558	464	MPC/SDGE
Bonanza 1	15S/14E/Heber	3/73	5024	?	Magma Energy, Inc.
Sharp 2	16S/16E/Mesa	3/73	6493	?	Magma Energy, Inc.
Fed-Rite 1	17S/16E/Heber	4/73	5380	?	Magma Energy, Inc.
Mesa 6-2	16S/17E/Mesa	8/73	6006	369	Bureau of Reclamation
Sharp 3	16S/16E/Mesa	pending			Magma Energy, Inc.
Bonanza 2	15S/14E/Heber	pending			Magma Energy, Inc.

Notes: MPC is Magma Power Co.; SDGE is San Diego Gas and Electric; DWR is California Dept. of Water Resources; UCR is Univ. of California, Riverside; Chevron Oil Co. is a subsidiary of Standard Oil Co. of Calif.; Imperial Thermal Products is a subsidiary of Morton International; Earth Energy is a subsidiary of Union Oil Co.; Magma Energy is a subsidiary of Magma Power Co.; I.I.D. is Imperial Irrigation District.

Sources: [9], [10], [11], [12], [13]

"development of a large market for geothermal brine is essential for development of the lower Colorado basin geothermal potential. The only market evident for very large quantities of geothermal brine is for saline water conversion." [6, p. 5]

IMPERIAL VALLEY

The Imperial Valley occupies that part of the Colorado Desert which lies north of the International Boundary with Mexico, south of the Salton Sea, west of the Sand Hills, and east of Superstition Mountain. The delta of the ancestral Colorado River became Lake Cahuilla, named after the Cahuilla Indians. A change in the course of the Colorado caused the diversion of its delta to the Gulf of California so that the waters of the lake had receded by evaporation to a foot in depth by 1848 [7, p. 22-23].

The valley, actually a basin, has elevations which range from 234 feet below sea level at the Salton Sea (the present-day name for Lake Cahuilla) to +1000 feet at the foothill boundaries. Average annual rainfall is less than 3 inches and the average temperature is 73° F with temperatures exceeding 100° F in over 100 days of a typical year [8, p. 49]. Three major fault systems lie within the area -- the San Andreas, San Jacinto, and Elsinore faults. The area is tectonically active and over the period 1904 to 1964 there have been 30 earthquakes of magnitude greater than 5.0.

Surface thermal phenomena in the region have consisted of fumeroles near the Salton Sea, mud pots, and mud volcanoes which discharge mud, hot water, steam, and carbon dioxide [9, p. 31]. According to Rex ...

"The geothermal area is estimated to cover at least two million acres. There appears to be about 20,000 feet of sediment in the basin and if the lower 15,000 feet are filled with hot brine and we assume an effective average porosity of 10 percent, we would have three billion acre-feet of geothermal reserves or more than two hundred times the annual flow of the Colorado River." [6, p. 9]

GEOTHERMAL AREAS AND WELLS

Figure 1 shows the location of the seven known geothermal resource areas located within the Imperial Valley of California: the Buttes (which includes the Salton Sea geothermal field), Heber, Mesa, Dunes, Glamis, Border, and North Brawley anomalies. Geothermal wells have been drilled in four of these regions -- Buttes (first drilled in 1927) and Heber, Mesa, and Dunes (first drilled in 1972).

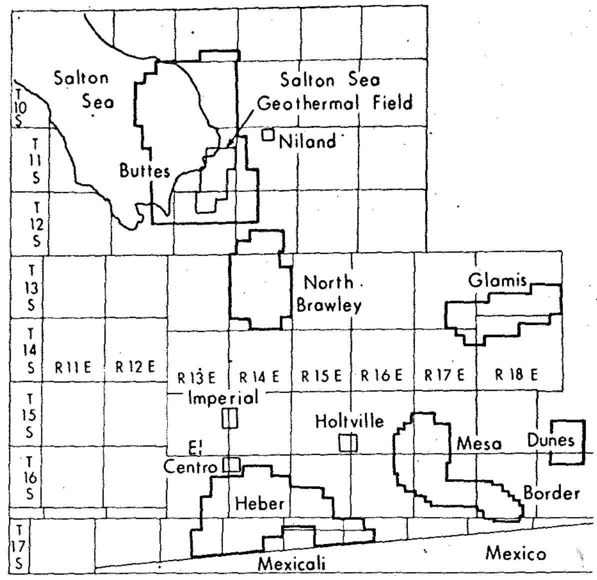

Figure 1. GEOTHERMAL AREAS (Imperial Valley, California)

Thirty-two geothermal wells have been drilled or are being drilled and these are listed in Table 1. Three periods of activity can be identified: 1927 to 1928 -- 3 wells; 1958 to 1965 -- 11 wells; and 1972 to 1973 -- 18 wells. Of the 18 recent wells, 14 have been drilled by Magma Power Company-San Diego Gas and Electric Company, or by Magma Energy, Inc., a subsidiary of Magma Power Company.

CHRONOLOGY OF DEVELOPMENT

1927 to 1928

The first three geothermal wells in Imperial Valley were drilled by Pioneer Development Company. These wells were adjacent to the extinct volcano known as Mullet Island where live steam and boiling water issued from mud pots. Although the sought-after steam was found, it was of insufficient pressure and volume and the geothermal steam search was abandoned, not to be resumed until 1958 when an oil well encountered hot geothermal brines.

The Pioneer Development Company's wells gave indications of an exploitable accumulation of carbon dioxide gas and the Salton Sea Chemical Products Corporation was formed and drilled three wells in 1932 to 1933. The second of these wells, a 750 foot well drilled in

October 1932, is considered to be the "discovery well." A small plant was built with an initial rated capacity of ten tons of dry ice per day. The company's operations were taken over in 1935 by Pacific-Imperial Dri-Ice, Inc., which, in turn, was acquired in 1940 by Natural Carbonic Products, Inc.

From 1934 to 1935 Imperial Carb-Ice Corporation drilled four wells and sold the gas produced to Salton Sea Chemical Products Corporation. In 1936 National Dri-Ice Corporation erected a plant in Niland with an initial rated capacity of ten tons per day of dry ice and the following year bought out Imperial Carb-Ice Corporation.

Through 1942, 66 wells were drilled in the Imperial Valley carbon dioxide field -- 54 encountered gas and 43 were commercial producers. The average life of a productive well was two years and production over the period 1934 to 1942 of CO_2 totaled 18,400,000 cubic meters (650,000,000 cubic feet, or approximately 40,000 tons of dry ice) [7, p. 30-32]. The field was abandoned in 1945 [5, p. 188] and drilling from 1945 to 1956 was confined to deep exploratory oil wells [5, p. 189-90].

1958 to 1965

In 1958 the Kent Imperial Oil Company drilled a deep exploratory oil well in a location five miles south of the 1927 to 1928 Salton Sea geothermal wells. The well, Sinclair 1, encountered 561° F brines at a bottom-hole depth of 4727 feet.

> *"Thereafter, oil and gas possibilities of the region were forgotten, and several companies were organized expressly to explore for geothermal steam."* [14, p. 8]

The Salton Sea (Buttes) geothermal system was discovered in 1961 [15, p. 304] when O'Neill Geothermal drilled Sportsman 1. The following year, O'Neill drilled I.I.D. 1. This mile-deep well yielded a very saline brine extraordinarily high in heavy metals and other rare elements (copper and silver) [16].

The following year (1963), Western Geothermal drilled Sinclair 3 and, in 1964, Sinclair 4. The latter well has been in operation, off and on, and produces calcium chloride concentrates by letting geothermal brines accumulate in surface ponds [10, May 1974]. In 1973 these two wells were taken over and are presently being reworked by Phillips Petroleum Company, signer of an agreement in 1972 with the Southern Pacific Land Company for geothermal development of the nearby 30,000 acres [10, November 1972].

The three wells drilled by Earth Energy, Inc. in 1964 (Table 1) produced large quantities of brine and steam and were used for a brine separation program by which the common table salt was precipitated out first, calcium chloride second, and potassium chloride (potash) third [11, p. 18].

Morton International, through its subsidiary Imperial Thermal Products, Inc., also had a mineral separation program as well as a 3,000-kw pilot geothermal steam generating plant. The solar evaporation ponding system of separation was used and the majority of the energy produced was sold to the Imperial Irrigation District (I.I.D.).

The Imperial Thermal Products well, I.I.D. 3, drilled in 1965, brought to a close the 1958 to 1965 geothermal well-drilling in Imperial Valley. Ten wells were drilled over the period 1961 to 1965 [17, p. 177] and eight of these wells produced hot brine from depths of 2952 to 5248 feet [5, p. 190], a brine which was described in 1966.

> *"The brine has a salinity of about 30 percent, consisting dominantly of sodium, calcium, and chloride but with very high contents of potassium, iron, manganese, zinc, lead, copper, silver, and other rare elements. Economic interest is focused about equally on the energy and potassium contents of the brine. Other by-products of value, such as lithium, silver, and other metals, may also be recoverable."* [17, p. 178].

A 1967 California report [11] estimated theoretical values per well-day of $30,000 for lithium, $5,000 for potash, $650 for zinc, $480 for borax, $280 for silver, $125 for lead, and $50 for copper.

The reasons for the loss of interest in the area after 1965 have been indicated by M. Goldsmith [18, p.8].

> *"In spite of the fact that many millions of dollars were invested in well drilling and production equipment, changes in the price structure of chemicals such as potash prevented the successful economic exploitation of the mineral resources. Experiments at producing electric power using steam from these wells were unsuccessful due to the highly corrosive nature of the mineralized brine. Because of this history, further exploration for geothermal resources in the Imperial Valley was inhibited for a number of years. While large quantities of water were obviously present, and heated to high temperatures, the mineral content of the water seemed an*

insurmountable obstacle to successful commercial exploitation."

1972-1973

Drilling resumed in the Buttes Salton Sea area near Niland when Magma Power-San Diego Gas and Electric drilled Magmamax 1 in 1972. Subsequently, four other wells were drilled nearby. Woolsey 1 and Magmamax 4 were drilled as producers, Magmamax 2 and 3 as injection wells, and Magmamax 4 as an observation well. Well 4 was taken as strong evidence of a major hot water reservoir and plans were accordingly finalized for eventual construction of the world's first binary fluid, closed-cycle power plant (10 MW) [10, December 1972].

Three wells have now been drilled in the Heber anomaly four miles south of El Centro, all in 1972. Two of these were drilled by Magma Energy, Inc. -- Holtz 1 and 2, and the third was drilled by Chevron Oil Company, Nowlin Partnership 1. In 1973 a joint venture agreement was made between Chevron Oil Company (a subsidiary of Standard Oil of California), Magma Energy, and New Albion Resources Company (a subsidiary of San Diego Gas and Electric) [10, October 1973].

Downhole pumps have been installed in Nowlin Partnership 1 and Holtz 1, which will be the production wells, and Holtz 2 will be the injection well for waste fluids:

"The downhole pumps are used to bring geothermal fluid to the surface at sufficient pressure to remain in the liquid phase. By preventing the geothermal water from boiling, Chevron hopes to prevent the scale buildup that has caused problems in wells and surface installations in other areas of the Imperial Valley. At the surface the hot water will be used to test an experimental binary cycle heat exchanger. The salinity of the geothermal fluid at Heber is similar to that at Cerro Prieto, Mexico (18,000 to 20,000 ppm). Bottom-hole temperatures at Heber are above 160^o C (320^o F)" [10, February 1974].

Exploration is now underway at the Dunes anomaly where the California Department of Water Resources and the University of California, Riverside (UCR) drilled a 2007-foot geothermal research well in 1972. The cores of this well will be analyzed as part of a UCR geological-geochemical-geophysical investigation [10, November 1972]. Research has been complicated by the existence of seven silica caps at the Dunes well and another well may need to be drilled [13, November 1, 1973].

The remaining area in which developments are taking place is the Mesa anomaly where the Bureau of Reclamation (BuRec) has drilled two deep geothermal wells -- Mesa 6-1 and Mesa 6-2. BuRec is in the research and development phase of a multipurpose program including demonstration and large-scale development stages. Cooperating agencies have included the State of California, U.S. Geological Survey, Office of Saline Water, University of California at Riverside, and Imperial Irrigation District [8, p. i]. Aspects of special interest include reinjection testing and geothermal desalting.

The danger of subsidence in an area with an established intricate irrigation system requires that recharge of the reservoir by injection be undertaken if large volumes of geothermal fluids are withdrawn for a desalting plant [8, p. 27 to 28].

In the latter part of the 1960's reinjection was tested in the Imperial Valley for a short period on a small scale [19, p.88] and results were promising. Tests by the Union Oil Company at the Salton Sea geothermal field indicated that concentrated waste geothermal brines can fall into the disposal well without any reinjection pumping, thereby effecting a substantial saving in waste disposal costs [20, p. 4].

Reinjection testing and technology will be combined in the Bureau of Reclamation project with geothermal energy production, desalination of the hot brines, and possible mineral recovery. The central emphasis, however, is that of a major water reclamation project:

"Stabilization of the salinity and level of the Salton Sea, reduction in irrigation-water salinity, provision of cooling for geothermal water and power plants, prevention of surface subsidence, and augmentation of the Colorado River flow are among the benefits to be expected from the proposed development of geothermal resources in the Imperial Valley" [1, p. 194].

SUMMARY AND CONCLUSIONS

Private enterprise has been the pioneer since 1927 in the exploration and development of geothermal energy and mineral recovery within the Imperial Valley. The corrosive and scaling nature of the geothermal brines have stymied large scale commercial development thus far, especially near the Salton Sea where salinities are close to 30 percent. In the past two years, however, drilling interest by both private and public organizations has been rekindled and, for the first time, wells have been drilled in the Dunes, Heber, and East Mesa geothermal areas.

A joint venture between Magma Energy, Chevron Oil, and San Diego Gas and Electric at the Heber anomaly appears to offer great promise for future developments. Although the temperatures of the geothermal fluids appear to be on the low side (under 400° F), both at Heber and East Mesa, the salinities are much less (close to 2 to 3 percent) than they were near the Salton Sea, and the Magmamax process which utilizes a binary fluid closed cycle power plant could conceivably represent the technological breakthrough that will open up the southern end of the Imperial Valley for geothermal power. The establishment of the feasibility of geothermal power will not only provide electrical energy for the Valley but will also enhance the prospects of the Bureau of Reclamation dual purpose geothermal power-desalting project at the East Mesa geothermal area.

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