LOW ENTHALPY GEOTHERMAL RESERVOIRS IN MEXICO AND FIELD EXPERIMENTATION ON BINARY-CYCLE SYSTEMS

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ABSTRACT

This paper considers a preliminary evaluation of the Mexican low enthalpy geothermal potential on the basis of the actually available geological and geochemical data. It also describes the most relevant aspects of the first field experiments carried out in México on geothermal binary-cycle systems at the geothermal field of Los Azufres, Michoacán.

INTRODUCTION

Because of its geographical location, México is a privileged country if we talk about geothermal resources. Nevertheless, high enthalpy geothermal reservoirs are not particularly common. For this reason, in many cases it is not possible to utilize conventional power generation systems for commercial exploitation purposes. Thus, in order to exploit such resources, nonconventional technologies will have to be applied, for example, binary-cycle plants.

In order to evaluate the feasibility of exploiting the low enthalpy resources, the Instituto de Investigaciones (IIE) is carrying out experimentations with binary-cycle pilot units for power generation, utilizing low pressure steam as well as waste brine.

LOW ENTHALPY GEOTHERMAL RESERVOIRS IN MEXICO

Low enthalpy reservoirs in México predominate over high enthalpy ones in an approximate ratio of 10 to 1 (Alonso, 1982).

More than 400 geothermal manifestations (Figure 1) have been detected within the country, a great many of which are located in the New Volcanic Axis (central part of the country). In most cases, the temperature of the brine coming from the source falls in the range of 40 to 60° C.

It is not easy to achieve a detailed evaluation for each geothermal manifestation. Thus, in this paper, a preliminary evaluation is shown on the basis of the detected manifestations equivalent area as well as considering a determinate action ratio.

The evaluation includes the New Volcanic Axis, which has an equivalent area of 900 km in length and 4 km in width. It also considers the northern and southern manifestations but excludes the Mexicali Valley, which equivalent area, 2000 km^2 including the Altar Desert and the Salty Lagoon, is evaluated separately.

PRELIMINARY EVALUATION

This evaluation is based upon the parameters utilized by Nathenson and Muffler (1975) in the U.S. Geological Survey publication titled "Assessment of Geothermal Resources of the United States."

The useful, low-enthalpy, geothermal-fluids temperature range to be utilized with binary-cycle technology now available varies from 90 to 150° C.

The calculation of the recoverable electric energy is based on the following parameters (Nathenson and Muffler, 1975):

(a) Valuation of the system's porosity and permeability;

(b) Valuation of the heat fraction stored in the permeable porous volume recoverable at the surface;

(c) Calculation of the well-head thermal efficiency that may be utilized in a power generation system.

From Nathenson and Muffler (1975, p. 106):

Q is the heat stored over 15° C, e_r is the recoverable factor. Thus, the production of electricity E is defined as:

$$E = KQe_r \qquad (a)$$

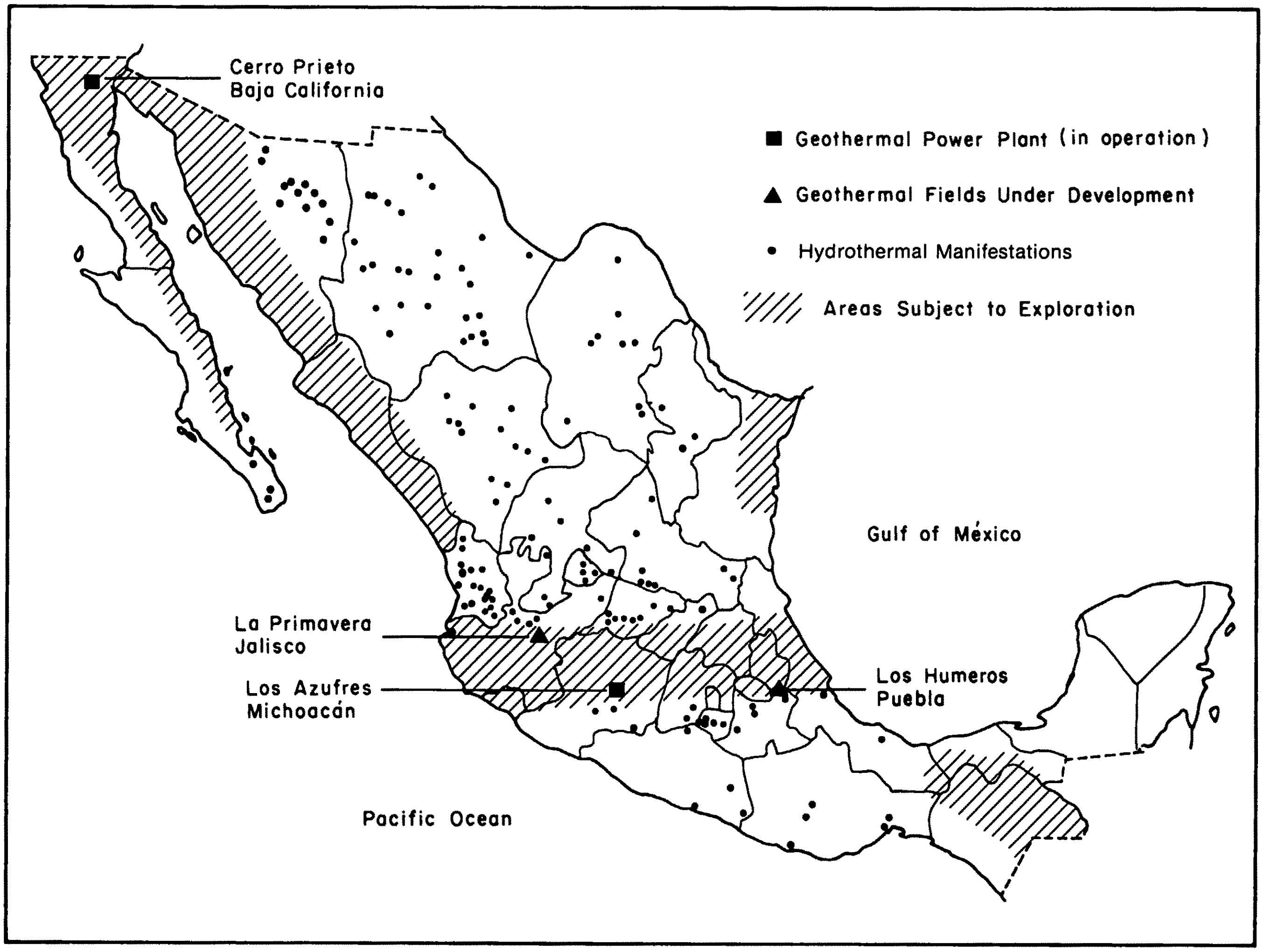

Figure 1. The Mexican geothermal resource

where

E = MWe Centuries
K (a constant) = 1327
Q = 10^{18} calories
e_r = recoverable factor.

The conversion factors shown in Table 1 are utilized for the conversion of stored heat into potential electric energy for convective hydrothermal systems with temperature over 150°C.

Technology for exploitation of medium and high temperature convection systems is currently available in México but technology for exploitation of low enthalpy reservoirs is being developed. The evaluation presented in this paper includes medium and low enthalpy systems and considers extrapolated recoverable factors (conversion efficiency of 0.06 for 100 to 150°C and a recoverable factor of 0.15), which lead to a gross estimation of the potential.

A sample calculation for the data shown in Table 2 (Acatlan, Jalisco, geothermal reservoir near Guadalajara) follows:

After silica determination of the different springs, we obtain a temperature of 127°C (silica geothermometer, column 3), but if we calculate the temperature on the basis of the NaKCa geothermometer we obtain a more precise temperature of 166°C (column 4). The NaKCa geothermometer is more accurate than the SiO_2 one because it adjusts the temperature value considering the mixture of the *spring waters* with rain water; thus we obtain 166°C for the subsurface temperature (column 4).

Table 1. Recoverable Factors for Electric Generation From Hot Water Systems (from Nathenson and Muffler, 1975)

Temperature Range °C	Conversion Efficiency	Recoverable Factor
150-200	0.08	0.02
200-250	0.10	0.025
250-300	0.12	0.03

The reservoir area is calculated considering the area delimited by the hydrothermal manifestations (column 6).

The reservoir volume 15.7 km³ is calculated with the already known area as well as the reservoir thickness, which is estimated to be 1.5 km, a value for the medium thickness of most of the geothermal reservoirs in exploitation around the world (column 8).

Table 2. Preliminary Evaluation of the Equivalent Areas for the Mexicali Valley and the New Volcanic Axis Geothermal Reservoirs

	Temperature (°C)			Reservoir Dimensions					Capacity
		Geothermochemical							
Reservoir	Surface	SiO_2	NaKCa	Sub-surface	Area (km^2)	Thickness (km)	Volume (km^3)	Heat Cont. (Cal 10^{18})	(MW_eC)
Acatlan (1)*	36	127	166	166	10.5	1.5	15.7	1.42	37
New Volcanic Axis (2)*	30-60	90-130	100-150	125	3600	2	7200	475	9459
Mexicali Valley (3)*	45-90	100-160	110-160	135	2000	1.5	3000	216	4299

* The expected capacity for 30 years of exploitation is 218 MW_e for (1), 31,498 MW_e for (2) and 14,317 MW_e for (3).

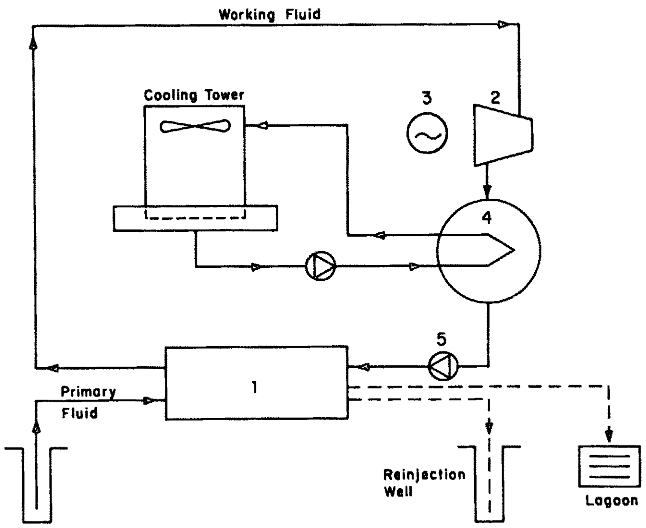

Figure 2. 50 kWe binary-cycle plant. See text for description of cycle.

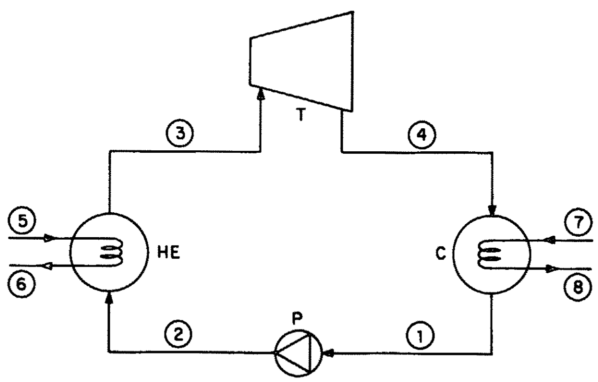

Figure 3. Flow diagram of the binary-cycle system. P = pump, HE = heat exchanger, T = turbine, C = condenser.

Considering all the data mentioned above, the heat content (column 9) is calculated:

$$(166-15)°C \times 15.7\ km^3 \times 0.6 \frac{calories}{cm^{3}°C} \times 10^{15} \frac{cm^3}{km^3}$$

$$= 1.42 \times 10^{18}\ calories$$

The reservoir capacity is calculated considering the heat content and the recoverable factor using equation (a):

$$1327\ (K) \times 1.42(Q) \times 0.02(e_r) = 37\ MW_e\ Centuries$$

In this way we obtain the data shown in column 10.

BINARY CYCLE PILOT PLANTS

A geothermal binary cycle is an organic Rankine cycle that utilizes a low enthalpy geothermal source as the primary fluid; the working fluid is a low boiling-point, organic fluid.

In order.to develop technology for the exploitation of the Mexican low enthalpy geothermal resources, the IIE has installed and is testing (Mercado and Fernandez, 1982) two binary-cycle pilot plants (50 kWe and 10 kWe) at the geothermal field of Low Azufres, Michoacan (New Volcanic Axis).

The main parameters considered for the installation and operation of the bianry-cycle pilot plants at Los Azufres are:

- The ratio between the steam-water mixture characteristics and the well's production.
- Brine characteristics: pH, chemical composition, specific heat, specific gravity in flow conditions.
- Separated steam characteristics: dragged salts and noncondensable gases content, quality in flow conditions.
- Climatic conditions: this was a very important parameter because in winter, low temperatures are quite common at the geothermal field.

Actually, turbines for binary-cycle plants are specifically constructed for their utilization with organic fluid vapors, such as freons, but freons are very expensive in México and considering this, the IIE is carrying out a research program in order to select the most convenient hydrocarbon as an alternative for the utilization of freons.

50 KW Binary-Cycle Pilot Plant

The 50 kW plant was designed and constructed by the ORMAT Company. Its working fluid is Freon 113 (R-113) and a diagram is shown in Figure 2. This plant has been installed at well No. 22 and the cycle may be described as follows:

The geothermal fluid transfers heat to the low boiling point organic fluid, causing its evaporation (1);

- The organic steam activates the turbine (2) which is attached to a generator (3);
- The organic steam is condensed (4) and recirculated (5) in order to complete the cycle;

Table 3. Operating Conditions of the 50 kWe Plant

	1	2	3	4	5	6	7	8
Phase	Sat. Liq.	Sat. Liq.	Sat. Vap.	Oversat. Vap.	Sat. Vap.	Sat. Liq.	Liq.	Liq.
Temperature °C	37	37	96	62	115	115	21	29
Pressure. kg/m²	7382	40,769	40,769	7382	17,556	17,556	31,636	2109
Enthalpy kcal/kg	16	16	60	55	644	115	21	29
Entropy kcal/kg °K	0.061	0.061	0.18	0.18	1.71	0.35	0.074	0.102
Mass Rate kg/hr	12,641	12,641	12,641	12,641	1100	1100	64,746	64,746

- The waste geothermal fluid is reinjected or diverted into an evaporation lagoon;
- There are two cooling-water systems for the plant. The first one is a closed circuit, including a cooling tower and a circulation pump as the main components. The other one is a single 5 H.P. pump installed at the Agua Fria River.

The preoperational tests have been carried out with low pressure geothermal steam as the primary fluid because the heat exchanger is not designed for operation with waste brine. Later on a new heat exchanger, designed for operation with waste brine will replace the steam one and the operating conditions as well as the plant efficiency will be compared.

Figure 3 and Table 3 show the operating conditions of the several cycle stages. The plant efficiency, 5.3 percent, has been calculated on the basis of these data and considering the water cooling system.

The plant has been operated 600 hours. The reported efficiency for the R-113 cycle is 12 percent. The main problems concerning the preliminary evaluations were involved with the lubrication and control systems as well as with the cooling tower. Despite these problems the plant was generating power and the obtained results are very important because this has been the first formal research program regarding feasibility studies for low enthalpy geothermal resource exploitation.

10 KW Binary-Cycle Pliot Plant

The 10 kWe plant may be defined as a "toy plant" and it is ideal for research because it is very easy to handle. The plant is being tested with waste brine as the primary fluid and Freon 12 (R-12) as the working fluid. A preliminary efficiency of 8 percent has been calculated for the R-12 cycle and the plant efficiency is 4 percent. The main problem has been scaling due to the high content of silica.

FLUIDIZED-BED AND DIRECT-CONTACT HEAT EXCHANGERS

The most important problem for the utilization of geothermal waste brine as the primary fluid for a binary cycle is scaling, mainly silica. In order to avoid this problem, a research program is being carried out at the IIE concerning fluidized-bed and direct-contact heat exchangers. The first testing period has been completed with the fluidized-bed heat exchanger, reporting an absence of scaling and a heat transfer coefficient two to four times higher than that obtained from a conventional heat exchanger.

During the second testing period and empirical correlation will be obtained in order to improve this new technology. On the other hand, a direct-contact heat exchanger is now under construction and will be tested soon.

CONCLUSIONS

The estimated value of the Mexican low enthalpy geothermal resource is 46,000 MWe, which is of considerable importance, and if exploited, may contribute in a significant way to the development of the country. In order to achieve this exploitation the first step carried out through the field testing with binary-cycle plants must be continued as well as the laboratory experiments with liquid fluidized beds and direct-contact heat exchangers.

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