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Rural Electrification in Mexico from Low Entalphy Geothermal Resources: Maguarichic Off-Grid Power Plant, Mexican Experience

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ABSTRACT

The Maguarichic geothermal project is a typical prospect under operation off-grid in a rural area and the experiences gained during the exploitation of the geothermal reservoir, construction and operation of the plant are presented. The benefits for the community of a continuous electrical supply are also presented. Recommendations based on this experience are expressed on how to install these plants easily, how to drill the wells and how to improve the technology to reduce the operation problems in rural areas where spares and other requirements may be very difficult to obtain.

1. INTRODUCTION

In Mexico, electrical generation is a federal responsibility. Comisión Federal de Electricidad (CFE) is the public agency responsible for generation, transmission and distribution of the electricity in the country. 96% of Mexico's population has electric service. Unfortunately, the remaining 4% includes villages with less than 100 inhabitants, located far from transmission lines [(1)].

CFE, through la Gerencia de Proyectos Geotermoeléctricos has identified more than 30 low and moderate enthalpy geothermal prospects located mainly in the Baja California Peninsula, in the northern part of the country (Chihuahua and Sonora states) and in the middle of the Mexican Neovolcanic Belt where Michoacán, Colima and Nayarit present several excellent prospects (Figure 1). This source of energy, located in rural areas, can be a part of the solution to supply electricity to the 4% of the population without electricity through off-grid, small scale projects using geothermal energy..

However, there are important technical and economic challenges to solve before going into a large program to develop this geothermal resource. The most important are:

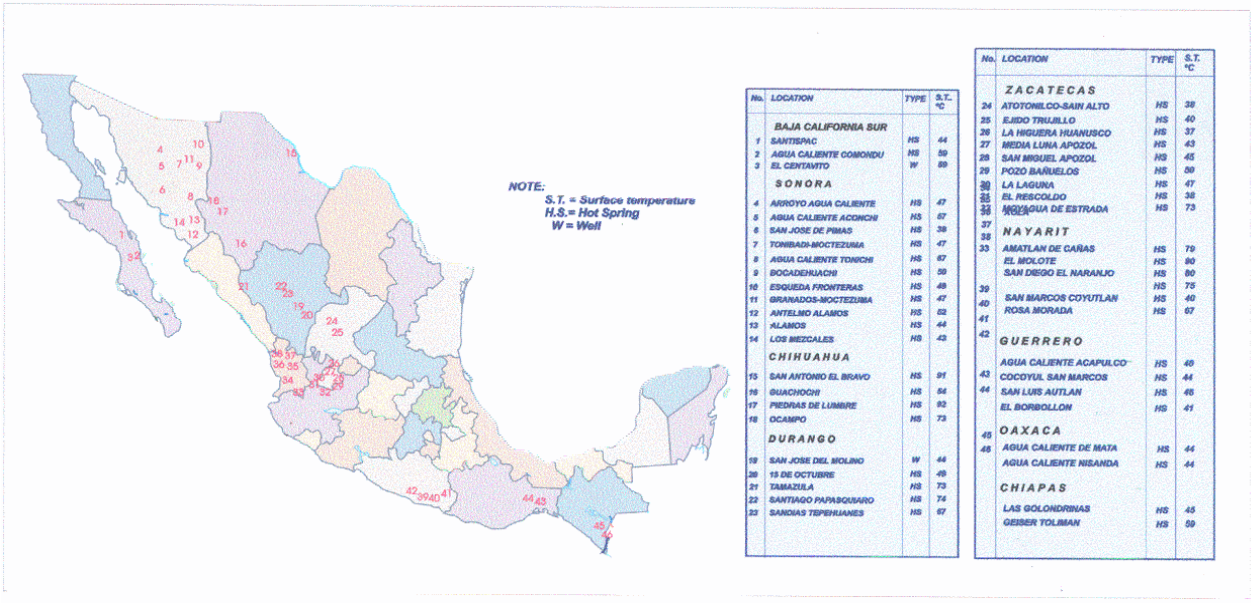
Site Access.- Most of the rural roads in México are narrow and cut across often steep terrain. Heavy truck and equipment access to areas served by these roads is very difficult.

Rig Characteristics - The rig characteristic is very important, because large rigs are impossible to transport through the narrow access, and very expensive. It is important to drill the well with a self-transporting rig.

Casing Design - The casing design depends on the assumption of a pump being installed into the well. This decision must take into a count not only the self-discharge but also the thermodynamic characteristics of the geothermal fluid and the possible evolution of the reservoir.

Power Plant Capacity - The capacity of the power plant depends mainly on the reservoir temperature and the electrical need of the consumption center.

Reliability - This is probably the most important challenge, because the operation of the sophisticated power plant, auxiliary equipment with electronic components, without extensive maintenance and without experienced technicians is the key from the technical and economical point of view of the project.



No.	LOCATION	TYPE	S.T. °C
	BAJA CALIFORNIA SUR		
1	SANTISPAC	HS	44
2	AGUA CALIENTE COMONDU	HS	59
3	EL CENTAVITO	W	89
	SONORA		
4	ARROYO AGUA CALIENTE	HS	47
5	AGUA CALIENTE ACONCHI	HS	67
6	SAN JOSE DE PIMAS	HS	38
7	TONIBABI-MOCTEZUMA	HS	47
8	AGUA CALIENTE TONICHI	HS	67
9	BOCADEHUACHI	HS	59
10	ESQUEDA FRONTERAS	HS	48
11	GRANADOS-MOCTEZUMA	HS	47
12	ANTELMO ALAMOS	HS	62
13	ALAMOS	HS	44
14	LOS MEZCALES	HS	43
	CHIHUAHUA		
15	SAN ANTONIO EL BRAVO	HS	91
16	GUACHOCHI	HS	54
17	PIEDRAS DE LUMBRE	HS	92
18	OCAMPO	HS	73
	DURANGO		
19	SAN JOSE DEL MOLINO	W	44
20	15 DE OCTUBRE	HS	48
21	TAMAZULA	HS	73
22	SANTIAGO PAPASQUIARO	HS	74
23	SANDIAS TEPEHUANES	HS	67

No.	LOCATION	TYPE	S.T. °C
	ZACATECAS		
24	ATOTONILCO-SAIN ALTO	HS	38
25	EJIDO TRUJILLO	HS	40
26	LA HIGUERA HUANUSCO	HS	37
27	MEDIA LUNA APOZOL	HS	43
28	SAN MIGUEL APOZOL	HS	45
29	POZO BARUELOS	HS	59
30	LA LAGUNA	HS	47
31	EL RESCOLDO	HS	38
32	AGUA DE ESTRADA	HS	73
33	NOGA		
34			
35			
36			
37			
38	NAYARIT		
39	AMATLAN DE CAÑAS	HS	79
40	EL MOLOTE	HS	80
41	SAN DIEGO EL NARANJO	HS	80
42		HS	75
	SAN MARCOS COYUTLAN	HS	40
	ROSA MORADA	HS	67
	GUERRERO		
43	AGUA CALIENTE ACAPULCO	HS	40
44	COCOYUL SAN MARCOS	HS	44
45	SAN LUIS AUTLAN	HS	46
46	EL BORBOLLON	HS	41
	OAXACA		
47	AGUA CALIENTE DE MATA	HS	44
48	AGUA CALIENTE NISANDA	HS	44
	CHIAPAS		
	LAS GOLONDRINAS	HS	45
	GEISER TOLIMAN	HS	59

In 1995 Comisión Federal de Electricidad began with a pilot project to produce electricity from the geothermal brine considering prospects where the reservoir could be located not deeper than 500 m. In 1997 CFE commissioned four binary units of 300 kW net capacity each to install in rural areas.

One of these units was installed in Maguarichic, Chihuahua. This paper describes various steps to the success of the project and how problems were solved.

2. LOCATION OF THE PROJECT

The geothermal prospect is known as Piedras de Lumbre located 6 km far from Maguarichic village. This is the consumption center.

Maguarichic is located in the southwestern part of the Chihuahua State, in the high Tarahumara Sierra, 350 km from the Chihuahua City. Maguarichic is a small village with 600 habitants. Beautiful landscapes are observed from this point with a dense forest and impressive massive rock. This is also an important potential site to exploit many tourist attractions. However, because the village is located 75 km from the transmission lines, providing electricity to Maguarichic from the power grid is not economically possible. Until 2001, power for the village was provided for only a few hours each evening, from 19:00 to 22:00, by an old polluting diesel generator at an elevated price per kilowatt-hour. The resources to run this plant came from the local authorities and from a federal fund to support depressed villages.

To travel from Chihuahua, the capital of this state, to Maguarichic, it is necessary to spend 6 hours driving, most of the time on rustic roads (Figure 2).

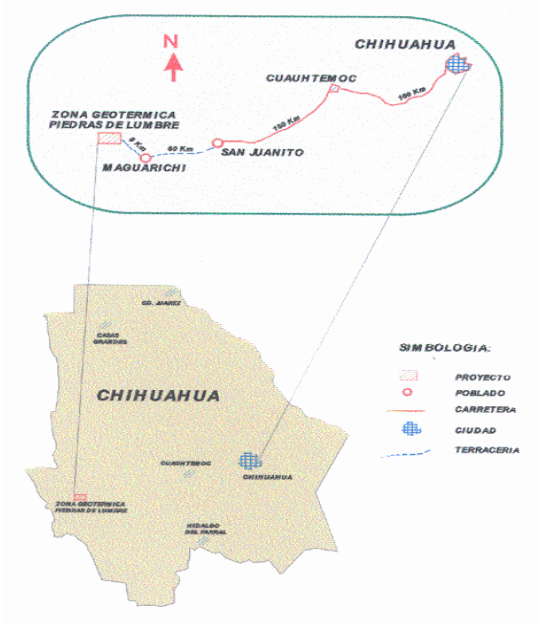


Figure 2. Location of Maguarichic in Chihuahua State

3. MAIN CHARACTERISTICS OF PIEDRAS DE LUMBRE

Six kilometers from Maguarichic, there is a site known as Piedras de Lumbre (fire stones), a typical geothermal site, with hot springs. In 1966 CFE began to explore this zone. The geothermal activities are related to the Basin and Ranges Rift, the water from the surface manifestations shows a sodium-chloride composition at a temperature calculated with geothermometers, of 130 °C (2). CFE developed an extensive geological survey to have a better view of the geothermal characteristics of this beautiful zone.

4. DRILLED WELLS

Before running resistivity surveys, CFE decided to drill a slim hole at 100 m. depth to gather better information on the reservoir thermodynamic characteristics. The well PL-1 was drilled using a self-contained rig finishing a 3½" diameter hole. The maximum depth was 49 m and produced hot water at 120°C. With this information and the temperature and pressure logs, it was possible to drill a second well, PL-2, with a 9 5/8" casing to 35 m and slotted liner to 300 m. Well PL-2's target was to gain even higher temperature and more production.

PL-2 did not present higher temperatures than that measured in the PL-1, with 35 t/h of hot water. With this positive result, CFE decided to install one of its small binary geothermal power plants, at a total cost of approximately (US$)$1.3 million. Federal, State and Municipal funds financed the project, and the community provided in-kind services.

5. BINARY POWER PLANT

In order to develop the low enthalpy geothermal resources in the country, CFE commissioned four binary units to have access to better prices, two of them air-cooled and the others water-cooled. Because the weather in Maguarichic was favorable for the water-cooled unit, CFE decided to install one of the water-cooled power plants. In this kind of unit, water is needed to replace evaporation. In Maguarichic this problem was solved by feeding geothermal water from the discharge of the heat exchanger. This condition was input for the cooling tower manufacturer. Because of the chemical characteristics of the geothermal water, with a high purity and low salt content, it was decided to eliminate any treatment for the water in the cooling tower.

The main characteristics of the unit are as follows: (3)

Type: Binary power plant (isopentane-geothermal brine)

Net capacity:	300 kW
Flowrate:	55 t/h with water at 150 °C.
Turbine speed:	3600 rpm
Gearbox:	2:1
Condenser:	shell and tubes
Cooling water:	400 t/h
Inlet cooling water temperature:	21°C.

Modular cooling tower with integrated basin

8 fans driven by electrical motor 4 kW each, located at the bottom of the tower

Synchronous generator

Output voltage:	|480 V
Generator speed:	1800 rpm

Unattended control and fully automatic

Non redundancy on the critical parts. The unit must stop if any problem is detected. This condition was established to reduce the power plant cost.

Fully factory assembled on the skid for the turbine, generator and condenser. Control room fully assembled and factory tested .

Auxiliary equipment: air compressor, diesel generator for the starting process.

The characteristics of the electrical system in Maguarichic are as follows:

Substation: 480/13,800 V

Transmission line: 6 km in straight line from Piedras de Lumbre to Maguarichic.

Distribution grid: 75 KVA

5 transformers 13800/125-220 V

6. COSTS OF THE PROJECT

This is a summary of the associated costs of this project, considering the main activities.

..	US$
Access conditioning	50,000
PL-1 (slim hole 49 m depth)	50,000
PL-2 (production well)	100,000
Pumping system	40,000
Erection works	50,000
Isopentane	10,000
Transmission line and distribution grid	75,000
Total	375,000

Main Equipment

Power plant	900,000
Cooling tower	60,000
Substation	10,000
Total	970,000

7. PROBLEMS TO SOLVE

The main problems encountered in developing the Maguarichic project and their solutions are presented below, with brief description of technical aspects.

7.1. Access

The original access road from San Juanito to the village (78 km) was narrow, cutting through steep terrain with many difficult curves. From Maguarichic to the Piedras de Lumbre (6 km) the road was unsuitable for heavy traffic. It was necessary to broaden the turns and improve the surface with gravel. The cost for this task was around 50,000 USD.

7.2. Traffic with heavy equipment

Because the turbine, generator, heat exchanger and condenser were mounted on a common skid and the total weight was around 28 tons, it was necessary to disassemble the condenser and the heat exchanger in San Juanito for separate transport, because in some places the road grade was greater than 15 percent (Figure 3). During some segments of power plant transport, it was necessary to assist the truck overcome the steep road by pulling it with a tractor.

Most of these activities were made without the support of special machinery because San Juanito is also a small village dedicated to forestry.



Figure 3.- Heat exchanger disassembly to reduce the weight of the generation module

7.3. Drilling Activities.

After completion of exploration activities, the next step was drilling of one well. The focus was on the technical problem of the rig characteristics required to pass through a difficult access. CFE normally drills wells with large rigs powered to reach 3000 m depth. This kind of rig is not the best option for this application. In Maguarichi, drilling took place with a self-contained rig, with 1000 m depth capacity. Well PL-1 was drilled with this kind of rig, but at 49 m depth the well encountered artesian water pressure and the rig was not equipped with a control system. For the next production well, and since the truck base was not high enough for installation of blowout prevention equipment, the truck was mounted on a platform (Figure 4). In this way the well was drilled without any problem and totally under control.



Figure 4. Self contained rig with platform for blowout prevention equipment installation.

7.4. Decreasing Temperature.

Because the pressure in the reservoir was 5 bar saturated water, the temperature was 120º C and the well produced single-liquid phase; the flashing point was recorded at 15-m depth. From this depth to the surface the temperature dropped to just 105ºC. To solve this problem, two solutions were tested:

- Inject a small amount of air below the flashing point.
- Install an electrical pump.

Both solutions were evaluated and technically were acceptable. However, the electrical pump was selected because the operation and maintenance would be much easier than the airlift.

7.5. Qualified workers

During the different steps of the project, qualified workers were needed to disassemble and assemble the main equipment on the rig, and install the different systems of the plant. Also the experience included the operation of the power plant with these people. Because of the remoteness of the area, foreign workers are not able to work there. In this case, CFE decided to contract people from Maguarichic from the beginning and train them with the supervision of CFE engineers. People from the village are now successfully operating the Maguarichic power plant. They have only a high school education.

8. OPERATION AND MAINTENANCE WORKS

The power plant was commissioned on April 30 2001 (Figure 5). Since CFE technicians are headquartered in Morelia, about 1000 km from the village, local residents were also trained on basic operation of the unit, including start-up, resetting of alarms, checking main readings and restarting. If a major problem occurs, CFE engineers go to the site.



Figure 5.- General overview of the power plant

During three years of experience CFE personnel assisted with problems encountered on:

- Problems with the automatic start up of the air compressor.
- Problems with the actuator of the brine stop valve.
- Problems with the salt deposits in the cooling tower.
- Problems with the well pump bushings.

Most of the time the problems have been solved by the local people, such as:

- Problems in the air compressor because of condensate in the filters.
- Problems with the condenser pressure, because of vacuum leakage.

9. SOCIAL IMPACT OF THE PROJECT.

This is probably the most important issue surrounding the Maguarichic project.

Before the continuous electrical supply the village had little public lighting; the streets were of gravel and without sidewalks. Households were connected without breakers directly to the diesel motor with serious electric leakage; electrical consumption from the diesel generator readings was 90 kW.

The village had no refrigeration because electricity was available only in on an infrequent basis and consequently they rarely consumed meat, cheese, milk, etc. Local children had never seen ice cream. Because of voltage variations there were no televisions, disconnecting people from the march of domestic, national and international events. But electrification brought almost immediate change.

When people knew of the geothermal project, the authorities decided to install a public lighting system, with nice lamps, sidewalks and paved streets. The community formed a committee responsible for the operation and maintenance of the power plant as well as the distribution of electricity. They decided to install meters at homes and obligate breaker installation. With the new distribution system and improvement in the home installations, consumption decreased to 35 kW, showing that they had had more than 100% of electrical leakage before. At the present time, the consumption has grown to 75 kW, the value three years before of the plant began operation.

This growth is due mainly because people decided to buy refrigerators, some bought televisions, in the village they now have a “tortilleria”, where the tortillas are made by an electric machine and the community has installed electrical swing machines to teach girls this skill.

The village is growing, as people who want the benefits of electricity and the work and business opportunities it provides, move to Maguarichic from nearby villages.

10. TECHNICAL CONSIDERATIONS

With the experience gained at Maguarichic, CFE has learned a number of answers to technical and economic questions that will be taken into account for similar, future projects in Mexico.

10.1. Regarding the geothermal reservoir

The aquifers to be exploited should be located preferably at depths of 500 m or less, so wells can be drilled with a small rig.

To acquire reservoir information, it is better to drill a production well instead of a slim hole. Costs are almost the same but a slim hole probably can not exploit a reservoir because of its inability to accept a downhole pump if necessary.

The minimum reservoir temperature could be 115-120°C. Lower temperatures increase water needs, demanding more

than one well to supply the required flow. Under these conditions the flow rate is 150 t/h for the 300 kW.

Lower temperatures require more flow, and the size of the heat exchangers must be greater. Also, most than one well is required, increasing the cost of the produced electricity.

10.2. Regarding the power plant

It is important to develop a water-water binary cycle and test its reliability. Transporting isopentane to an isolated rural area is very difficult because, at least in Mexico, it is considered as a dangerous material. To replace leaked fluid (around 7% per year) it is necessary to rent a special transport vehicle with higher cost than the fluid (US$5,000 of the truck compared with the US$2,500 for the isopentane).

The plant should be designed to operate over a range of inlet brine temperatures (120-135ºC). This range covers several site conditions to operate without problems. The Maguarichic power plant was designed for an inlet temperature of 150°C but available geothermal fluids are only 120°C. By increasing the flow rate the plant can produce 200 kW output but will never reach the equipment's rated 300 kW.

The generation skid must be designed in a modular fashion with a maximum weight of 15 tons per module. Heavier modules must be disassembled to transport them on a rough, steep road.

The heat exchangers should be designed for a maximum length of 9 m to avoid transportation problems.

The main isopentane pump should be horizontal instead vertical to reduce the civil works.

The assembly between the turbine and generator should be direct instead of through a gearbox, which is noisy and requires maintenance.

Power capacity should be sized correctly and higher than the electrical consumption, in order to support a consumption increase. Too large of a difference between power capacity and consumption in the initial step can make it uneconomical. Too small a difference between capacity and consumption can also constrain desired economic development associated with electricity generation.

10.3. Regarding the economy of the project

Three people from Maguarichic handle power plant operation and maintenance activities. Operational costs were less than $8,000 (US) during these years. CFE spent a similar amount for supervisory work.

The plant is on line and households pay an average of $4 (US) per month for their electric consumption, since the villagers cannot afford the actual cost of the electricity. Local authorities helped by paying the salaries of the three power plant workers.

In developing countries, these types of rural electrification projects must be financed by government agencies, but the community must also be involved and support at least a small share of the costs.

11. CONCLUSIONS

The Maguarichic project has been on line since April 30 2001, with good reliability.

Different problems have been presented and solved during the construction and operation of the project.

The experience gained by CFE in this project led to better knowledge in the exploitation of low temperature geothermal resources.

This kind of project has an important impact on the social and economical development of the small villages.

These kinds of projects are not designed for private investors or to make money, because of the investment cost requirements and the difficulty in selling the electricity in rural and poor villages at a realistic price.

The participation of government agencies in this kind of project is very important to support them.

The local community must be involved participating in at least a small share of costs, otherwise they will require federal help for the smallest problem in the power plant, increasing the supervision costs and the interest of the federal agencies in sponsoring this kind of projects.

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