Desalination Using Geothermal Energy

H. Aviña-Jiménez, D. De la Rosa-Urbalejo, and A. García-Gutiérrez

iiDEA, Engineering Institute, National Autonomous University of México (UNAM)
Torre de Ingeniería 6° Nivel, Circuito Escolar, Ciudad Universitaria 04510 Ciudad de México, México
havinaj@iingen.unam.mx • ddelarosau@iingen.unam.mx

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ABSTRACT

A detailed analysis of the potential commissioning of seawater desalination technologies by using geothermal energy is presented. The suitability of locations and their feasibility to install this technology are discussed with emphasis on Baja California, Mexico.

Three main requirements must be combined to install seawater desalination technologies: the geothermal potential at a site, the need of fresh water under a shortage scenario, and access to seawater. Due to these constrains, few sites in the world offer these three requirements in which the use of geothermal energy for seawater desalination can be used. However, Mexico can deal with these constrains offering the possibility of studying, analyzing, developing and optimizing this concept.

Sites located in Baja California Peninsula such as Ensenada, Puertecitos, San Felipe, San Quintín, La Paz and Los Cabos satisfy all these requirements in order to test and install portable systems for electric generation and desalination.

Introduction

The iiDEA group, an applied research group part of the National Autonomous University of Mexico (UNAM) is focusing on low-enthalpy direct uses of geothermal resources in Mexico. For more than 60 years geothermal resources have been exploited in the country; however, the vast majority of the applications are concentrated on power generation. Mexico has the fifth largest installed geothermal capacity in the world [1]. So far, almost the entire geothermal power production has been in charge of the Federal Electricity Commission (CFE), which exploits four geothermal fields: Cerro Prieto, Baja California, with an effective installed capacity of 570 MWe out of an installed capacity of 720 MWe; Los Azufres, Michoacán, with 221.6 MWe, Los Humeros, Puebla, with 93.6 MWe, and Las Tres Vírgenes, Baja California Sur, with 10 MWe. In addition, in February 2015 Grupo Dragón part of the Grupo Salinas consortium installed two 5 MWe units in Domo San Pedro, Nayarit. Moreover, the installation and commissioning of a new 25 MWe net capacity plant is expected in short future. This project represents the first private geothermal field in Mexico since the start of the Mexican Energy Reform along with the law and regulations on Geothermal Energy. The geothermal capacity in Mexico represents 2.6% out of the 38,000 MWe of installed capacity reported by the Mexican National Electric System (SEN) [2].

The geothermal fields can be classified depending on the physical state of the water, the purity of the water, the output pressure of the well, or the temperature of the fluid.

Commonly, geothermal resources can be classified by enthalpy, this means that the temperature of the fluids is taken as a reference of the heat transport from the reservoir to the atmosphere.

Normally high-enthalpy resources are used in power plants due to their high energy potential. On the other hand, medium-enthalpy reservoirs may be utilized in several processes, for instance, textile, metallurgical, and agricultural industries. Finally, low-enthalpy geothermal energy is used in domestic applications, such as air conditioning or thermal bathing pools.

In general, low- and medium-enthalpy geothermal resources (temperature: 60 - 150°C) for power generation do exist but are not utilized in Mexico. Direct use of geothermal heat is one of the most ancient, versatile, and common forms of utilizing geothermal energy. Some of the well known applications are thermal bath pools, local and district heating, agriculture, aquaculture, and industrial applications, as well as in heat pumps which is the major geothermal direct use application.

Figure 1 shows the temperature distribution of geothermal systems in Mexico, where 90% of the resources are in the 60°C to 150°C range, i.e. the low- to medium-enthalpy systems.

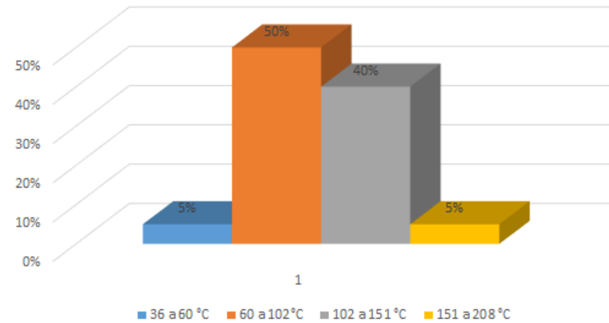

Figure 1. Percentage distribution of geothermal systems in Mexico classified by temperature [3].

Seawater Desalination Using Renewable Energies

In recent years, due to the development of new technologies and applied research in seawater desalination supported by renewable energies and conventional desalination plants (thermal and electrical), an important increase in efficiency and cost reductions have been obtained, resulting in a competitive scenario in which these techniques merge [4]. There are some demonstration plants worldwide which have applied this technology combination and obtaining distillation volumes of around 100 m^3/day [5]. Most of these projects (a combination of desalination systems with solar energy) have not had an industrial scale impact yet; however, they have cemented the foundations for new technologies and research towards the increase in efficiency.

It is important to note that not all renewable energies in combination with seawater desalination technologies are effective because there are many variables that have to be evaluated, such as geography, site topography, seawater quality, available infrastructure, capacity and availability of renewable energies. Mexico offers the right conditions to favor a successful implementation of the concept.

Seawater Desalination Using Geothermal Energy

Despite geothermal energy not being available worldwide due to its nature and geographical distribution along the fact that other renewable energies such as solar and wind are more utilized, geothermal energy possesses greater advantages over these two technologies such as the capacity factor of geothermal power plants which is above 80%. Furthermore, geothermal power plants in Mexico reach capacity factors of more than 90% with the following benefits: the resource can be continuously supplied, a natural thermal energy storage is available, the rate of extraction is predictable [6], and more importantly geothermal energy has the lower cost per MWh among other renewable energies, as Table 1 shows.

Table 1. Power generation costs by technology using renewable energies [7].

Energy	Cost 2010-2020 (US$2009 per MWH)			Cost 2021-2035 (Estimate) (US$2009 per MWH)			Renewable Development Index
	MIN	MAX	AVG	MIN	MAX	AVG	
Biomass	119	148	131	112	142	126	5%
Onshore wind	63	126	85	57	88	65	7%
Offshore wind	78	141	101	59	94	74	9%
Geothermal	**31**	**83**	**52**	**31**	**85**	**46**	**5%**
Large-scale solar photovoltaic	195	527	280	99	271	157	17%
Building-integrated photovoltaic	273	681	406	132	356	217	17%

High-enthalpy geothermal energy allows mechanical power transmission to the high pressure pump shaft of the desalination reverse osmosis units. On the other hand, medium- and low- geothermal enthalpy resources can be used in direct uses systems.

Direct use of geothermal energy for desalination plants is well-known and proven in some places; at the same time, considering the technological advances that increase heat transfer along with coatings that provide a better scale control and fouling resistance, temperatures of the geothermal fluid as low as 60°C can be used for direct uses, representing a promising solution [8]. In the following section some cases will be presented in which geothermal energy has been used as the main resource for desalination plants in several parts of the world.

Study Cases of Geothermal Energy Use for Desalination

The first study case took place in the USA in the 70's by using geothermal resource for Multi-stage flash (MSF) and Multiple-effect Distillation (MED) technologies [9]. In Algeria where the low-enthalpy geothermal fluid temperature reaches 98°C [10], a greenhouse in which the temperature of the seawater was increased utilizing the geothermal resource to obtain distilled water was built. This hybrid system was backed up by a solar energy system [11]. The only known case operated entirely by geothermal energy is the case of Milos, Greece. The island of Milos is located in the Aegean Volcanic Arc and it is characterized by the abundance of geothermal resources [12]. The objective of Milos' island project was to build and operate a low-enthalpy geothermal power plant using an organic binary cycle with a capacity of 470 kWe and an efficiency of 7%. This MED desalination plant at Milos was capable of producing 80 m^3/h with an estimated cost of 1.5 euros per cubic meter. The range of temperatures of the wells was between 55-100°C [13] with a depth range between 70-185 m supplying 550 m^3/h of geothermal fluid. The relevance of this project relies on the demonstration of the viability of coupling desalination technologies with low-enthalpy geothermal energy.

Study of Geothermal Resources in Baja California

The Engineering Institute and the Geophysics Institute of UNAM have implemented a technological development plan for geothermal resources evaluation and characterization of seawater or well water (60-140°C) in the Baja California Peninsula. The study located several sites where large amounts of water can be obtained at temperatures above 130°C coming from wells with depths between 100 and 200 m. One of the main goals is the identification of the best location for drilling a well capable of supplying hot water at temperatures close to 200°C [14]. As a result, several sites of interest were identified such as: Los Cabos, La Paz, Puertecitos, San Felipe, and Punta Blanca, among others, as shown in Figure 2. During the drilling of a well in Los Cabos, water temperatures up to 84°C were found at a shallow reservoir 6 m depth. This hot water spot is currently supplying a reverse osmosis desalination plant. In a similar way during a study that took place in Punta Blanca, brackish water springs at temperatures above 50°C were found at the surface [15].

During the exploration of the peninsula, it was found that La Joya, Ensenada, is one of the sites with the best low-enthalpy geothermal energy potential. In a more detailed exploration campaign temperatures up to 93°C at 1m depth were found [16].

These geothermal sites are of vital importance for seawater desalination using low-enthalpy geothermal fluids because the resource is located close to the sea, therefore, it increases the possibility of using seawater desalination utilizing geothermal energy.

Figure 2. Geothermal resources in the Baja California Peninsula.

Development of a Thermal Desalination Unit Using Geothermal Energy Proposal

The iiDEA group has as objective the design and implementation of seawater desalination systems using renewable energies to satisfy the water demand in certain locations of Mexico. By merging the aforementioned location of the low-enthalpy geothermal potential sites and the strategic geographical location of the Baja California Peninsula, these two key factors make feasible the installation of modular desalination systems.

By performing theoretical studies and commissioning a modified MED system prototype using geothermal resources, basic models for determining the configuration and operation of the system were proposed. Table 2 presents the results of the analysis undertaken using the modified desalination MED systems employing low-enthalpy geothermal energy as the thermal

Table 2. MED system parameters using low enthalpy geothermal energy [17].

	Parallel stream	In series stream	Configuration 1	Configuration 2	MED Low-enthalpy
Feed water [m^3/h]	66	54	359	71	**92**
Distilled water [m^3/h]	21.5	20.2	16.5	26.6	**27.8**
Recovery rate [%]	33%	37%	5%	37%	**30%**
Pump power [kW]	18.8	24.6	95.8	40.5	**26.7**

source for the desalination process. Several feed configurations were considered, using in series and parallel streams, as well as a combination of both.

It is important to note that these results were obtained from a preliminary thermodynamic analysis in which the seawater and geothermal fluid properties were considered to be that of fresh water. Moreover, the electric energy consumption necessary to operate the vacuum system that controls the evaporation process was not considered, however, these assumptions were appropriate for the implementation and configuration of the system.

The proposed model was named MED-LE (MED Low-enthalpy) to emphasize that a geothermal resources is used. The MED-LE has the same evaporation principle as a conventional MED system, however, the differences between them are in the arrangement and equipment used. Table 3 shows the operational characteristics of both systems.

Table 3. Operation characteristics of MED and MED-LE systems [17].

	MED	MED-LE
Energy source	Steam	Liquid low-enthalpy geothermal resource
Operation temperatures	<70°C	85°C
Energy consumption	First effect (evaporation chamber)	The geothermal resource is employed in the first effect. In subsequent effects and in heat exchangers the remaining energy is used
Vacuum system	Steam ejectors	Hydro ejectors, compressed air ejectors, turbochargers

A basic schematic representation of the MED-LE system is presented in Figure 3 where seawater evaporation takes place in a parallel stream configuration. It is important to note that the most important modification is that the hot water (heat resource) is not discarded, it is fed through the subsequent chambers transferring its energy to produce steam. This modification increases the process efficiency mainly by reducing energy consumption.

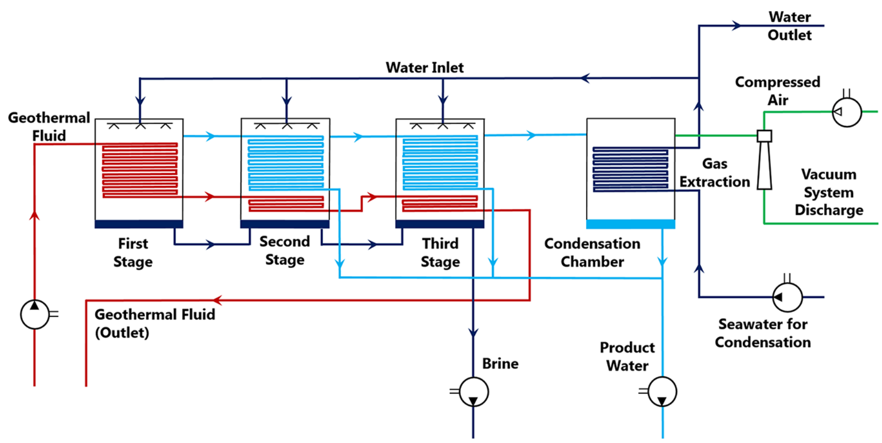

Figure 3. Low-enthalpy geothermal Energy MED LE desalination system schematic representation.

A known issue of this system is the fact that there is no driving fluid to generate vacuum conditions. The vacuum system allows modification of the evaporation temperature of the water favoring the two-phase mixture (vapor/seawater). Therefore, the use of a compressed-air ejector has been considered. Along with the thermodynamic analysis of the system the power needed to generate vacuum conditions has also been considered, leading to the eventual inclusion in the production costs.

Conclusions

There are certain limitation on the use of renewable energy technologies, such as geothermal, for seawater desalination and power generation due to its dependency on the main requirements that must be combined in order to install seawater desalination technologies. Due to these constrains, few sites in the world offer these three requirements. However, Mexico can deal with these constrains offering the possibility of studying, analyzing, developing and optimizing this application by covering all these requirements.

The MED-LE system represents an efficient option that employs renewable resources to produce distilled water, mitigating the shortage of fresh water in north western Mexico, and reducing the environmental impact associated with the combustion processes employed in other desalination technologies. Locations in Baja California Peninsula such as Ensenada, Puertecitos, San Felipe, San Quintín, La Paz and Los Cabos are suitable to test and install portable systems for electric generation and desalination.

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