Research Article **ISSN: 2581-4648** **Open Access**

UPI JOURNAL OF CHEMICAL AND LIFE SCIENCES

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Proposal for a Binary Cycle Plant for Power Generation in Ixtlan Delos Hervores Geothermal Field, México

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Abstract

The area of the Cienega de Chapala is located east rift Citala which houses a geological system that results in the regional hydrothermal activity, mainly Pajacuaran and Ixtlan failures. The regional geothermics consists of a shallow hydrothermal activity consisting of springs and wells of hot water with temperatures between 48 and 94°C in Ixtlan de los Hervores and San Juan Cosala well as mud volcanoes in Los Negritos. Water and gas hydrothermal manifestations have physicochemical characteristics that indicate the presence of geothermal fluids.

In this paper the Ixtlán de los Hervores geothermal area is studied, interpreting the hydrogeochemical characteristics of the water reservoir through diagrams Giggenbach, it was determined that are waters with high concentration in cation Na^+ (sodium) therefore could be classified as soft water. The Ixtlan de los Hervores geothermal field is considered a reserve of geothermal energy with a potential of 15 MW (in agreement with conventional technologies). Understanding the need for the use of geothermal energy as clean energy to minimize global warming and reducing the impact of climate change globally, a binary thermodynamic cycle for electricity generation is proposed at the present work.

The temperature of fluids on the surface is 98°C, based on which is proposed the basic engineering for a thermodynamic cycle binary type with a calculated efficiency of 87.67 % in order to give an utilization to the geothermal resource.

Key words: Geothermal field, Power generation, Binary Cycle Plant.

How to cite: José Martínez Reyes, IsraeL Gálvez Zamora, Ivan Vera Romero, Agustina Ortiz Soriano. Proposal for a Binary Cycle Plant for Power Generation in Ixtlan Delos Hervores Geothermal Field, México. UPI Journal of Chemical and Life Sciences 2018; 1(1): 12-21.

Article history:
Received : 13-03-2018, Accepted: 19-03-2018, Published: 20-03-2018

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1. Introduction

San Juan Cosala, Jalisco is located east rift Citala, housing to graben and Lake Chapala, the graben is bounded by a couple of flaws that allow geothermal activity in the region: the Pajacuaran and Ixtlan faults as (Figure 1) [1].

The Ixtlan fault is part of the northern flank of Chapala graben with a length of 30 km in NW-SE alignment along the bed of the Duero river, the fault is visible by a series of shallow hydrothermal manifestations [2-3], while the Pajacuaran failure is part of the southern edge of the graben with a length of 20 km in EW direction [3-4]. The stratigraphy of the area consists mainly of andesites and basalts of late Tertiary (Upper Miocene) to Quaternary (Pleistocene Superior) that outcrop south of the region interspersed with lake sediments, mainly limestones and dolomites of the Pliocene, which outcrop in the center west and north of the area [2-3]. The Cienega Chapala region is characterized by periods of volcanic activity in the past, and is precisely volcanic activity one of the geological precursors of mineral deposits and geothermal resources [5], reason by which is a convenient study of regional geothermal prospecting.

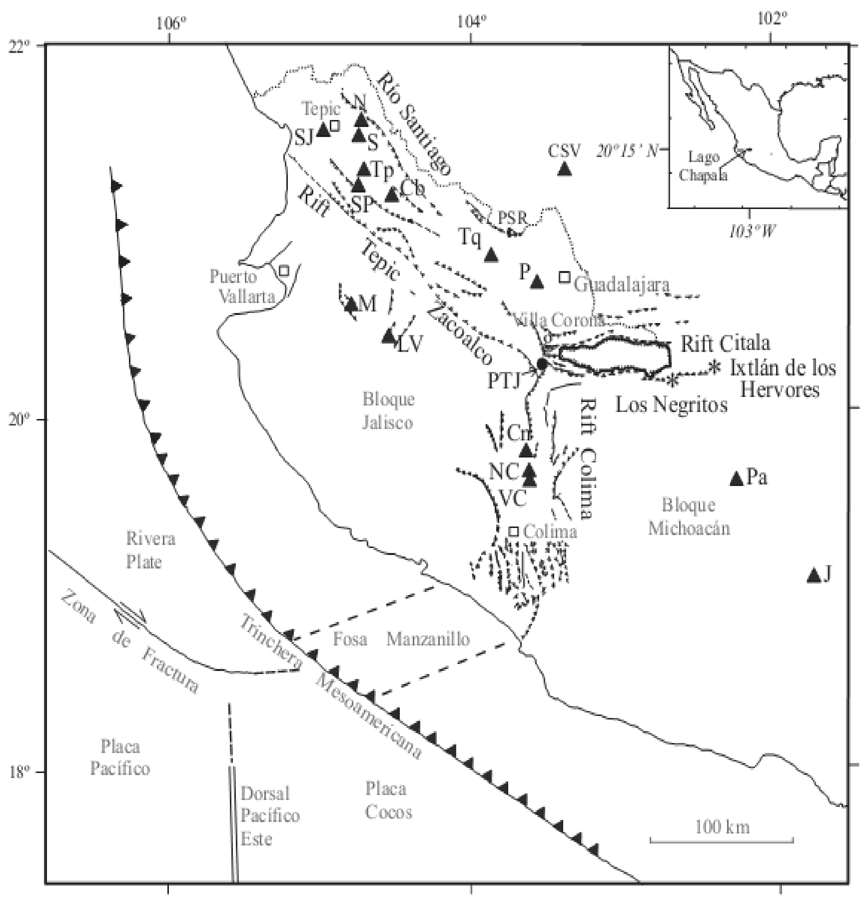

Figure 1. Regional geology of the Cienega de Chapala.

1.1. *Hydrothermal activity area*

The regional geothermics consist of a shallow hydrothermal activity consisting of springs and wells of hot water with temperatures between 48-94˚C in Ixtlan de los Hervores [3, 6-7] as well as mud volcanoes in Los Negritos [8]. Waters of the hydrothermal manifestations are mainly sodium chloride type containing boron indicating the presence of geothermal fluids, gases from manifestations thereof show a characteristic composition of geothermal gases. Geothermometers from both fluids indicate geothermal reservoirs of medium temperature (125-225˚C) for the area [3, 9-10]. Moreover, the waters show isotopic enrichment in oxygen-18 (18O) typical of geothermal environments [3, 10]. All the above features together, can be indicative a geothermal reservoir of wide fracture type (major failure breadth 100 m) of low relief with a phreatic level up to 3 m deep.

1.2. *Types of geothermal manifestations*

Generally, geothermal reservoirs are not closed systems, so there are surface discharges as springs, fumaroles steaming pits or acidic soils. It springs usually categorize as: mild/temperate, hot and boiling. Temperate springs are those whose temperature does not exceed 45°C.Hot springs have temperatures above 45°C and below the boiling point corresponding to the place. Boiling springs in most cases are associated with magmatic high temperature hydrothermal systems [11].

1.3. *Binary cycle geothermal power plants*

Binary cycle plants allow the use of low enthalpy deposits, i.e. geothermal resources from low to medium heat. In these plants, the geothermal fluid does not pass through the turbine generator, it transfers its thermal energy to a fluid organic low boiling (secondary fluid) through a heat exchanger. The organic working fluid is evaporated in the heat exchanger, and through a thermodynamic process (Rankine cycle) produces electrical energy when passing through a turbine coupled to a generator.

One of the biggest advantages of power generation obtained from geothermal resources is the fact that these plants have a very high capacity factor (annual operating hours in front of the total possible), much higher than other renewable energy technologies. Unlike other energy sources such as solar or wind, with strong seasonal or hourly units, a geothermal power plant can be fully operational, except maintenance needs, 24 h a day and 365 days a year [12].

2. Experimental

2.1. Methodology

2.1.1. *Ixtlan de los Hervores Giggenbach diagrams*

Data corresponding to the Ixtlán de los Hervores geothermal field from literature were taken, where the cation concentration was used, for geochemical modeling of the reservoir through Giggenbach´s diagrams and determine the hydrogeochemical features of the area , the results obtained by analysis diagrams will be presented in the chapter of results (Figure 2).

According to the ternary diagram proposed by Giggenbach, hot springs can be classified, based on relative contents of Na +, Ca ++, and Mg ++ and the relative concentrations of Cl^-, $SO_4^=$ and HCO_3^- [13].

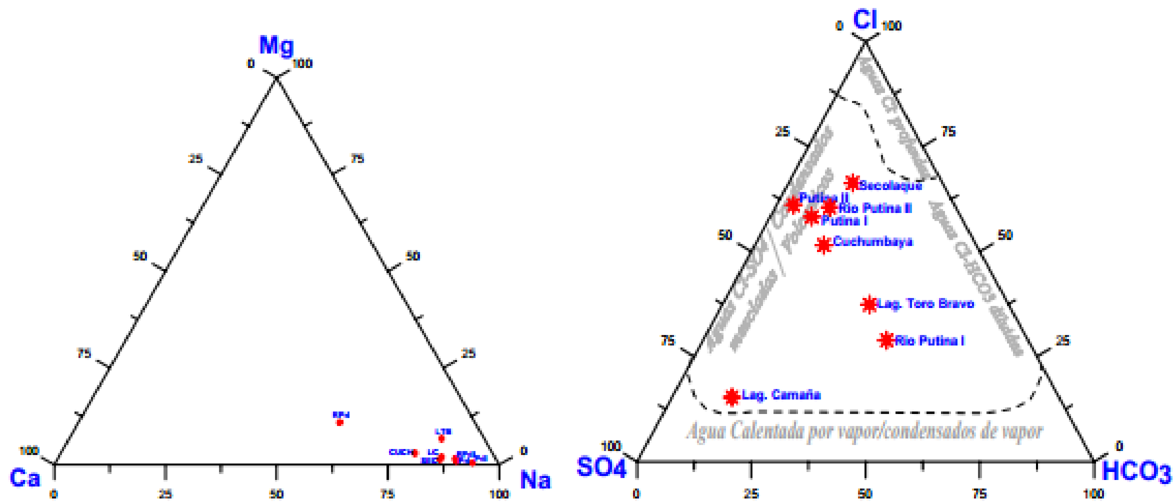

Figure 2. Giggenbach diagrams [Source: Brombach and co, [13].

According to the results in Giggenbach´s diagrams what type of water is determined are in the geothermal reservoir, when located at the top of the diagram have a high concentration of magnesium or can be chlorinated water, if they are in the bottom right have high concentration of sodium or carbonated and if it is in the bottom left have high concentration of calcium or sulfated waters.

The development of these diagrams will classify geothermal fluids sampled in Ixtlan del Rio geothermal field, if chlorinated water (Cl^-), sulfates ($SO_4^=$), carbonate (HCO_3^-), or if they have high concentration of Mg^{++}, Ca^{++}, Na^+ and according to conclude whether the results are of volcanic origin and if they come from deep water reservoirs that exist thanks to the presence of faults [14].

2.1.2. *Basic engineering or thermodynamic design of the binary cycle*

The technical proposal for Ixtlan del Rio geothermal zone is a binary cycle plant based on the Rankine cycle, which is ideal for steam cycle power plants, this cycle does not include any internal irreversibility, it consists of the following elements and processes [15]:

2.1.2.1. *Turbine:* The steam generated in the heat exchanger with high temperature and pressure expands in the turbine to perform work, and later discharged into the condenser at low pressure. The formula for calculating the turbine work is as follows:

$$\frac{\mathrm{Wt}}{\dot{m}} = \mathrm{h3} - \mathrm{h4} \qquad \text{Equation 1}$$

2.1.2.2. *Condenser:* In the condenser, the heat of the working fluid is transferred to a cooling fluid circulating separately, i.e. it is a rejection of the remaining heat in the working fluid cycle. The formula for calculating the heat output corresponding to the condenser is:

$$\frac{\mathrm{Qs}}{\dot{m}} = \mathrm{h1} - \mathrm{h4} \qquad \text{Equation 2}$$

2.1.2.3. *Pump:* The liquid leaving the condenser is pumped from the condenser pressure to the highest pressure of the heat exchanger. The formula for calculating the pump work is:

$$\frac{\mathrm{Wb}}{\dot{m}} = \mathrm{h2} - \mathrm{h1} \qquad \text{Equation 3}$$

2.1.2.4. *Heat exchanger:* Fluid completes work cycle when the liquid coming from the pump, is heated to saturation and evaporates or sometimes leads to overheating conditions. The formula for calculating the heat input from the boiler is:

$$\frac{Qe}{\dot{m}} = h3 - h2 \qquad \text{Equation 4}$$

For the design of the thermodynamic cycle power generation, the following are taken into the consideration (Table 1, Figure 3)

Table 1. Parameters for design of thermodynamic cycle power generation.

State of the thermodynamic cycle	Process
A	Geothermal fluid Input to heat exchanger
1-2	Isentropic Compression at pump
2-3	Adding heat at constant pressure
3-4	Isentropic Expansion in the turbine
4-1	Rejecting heat at constant pressure

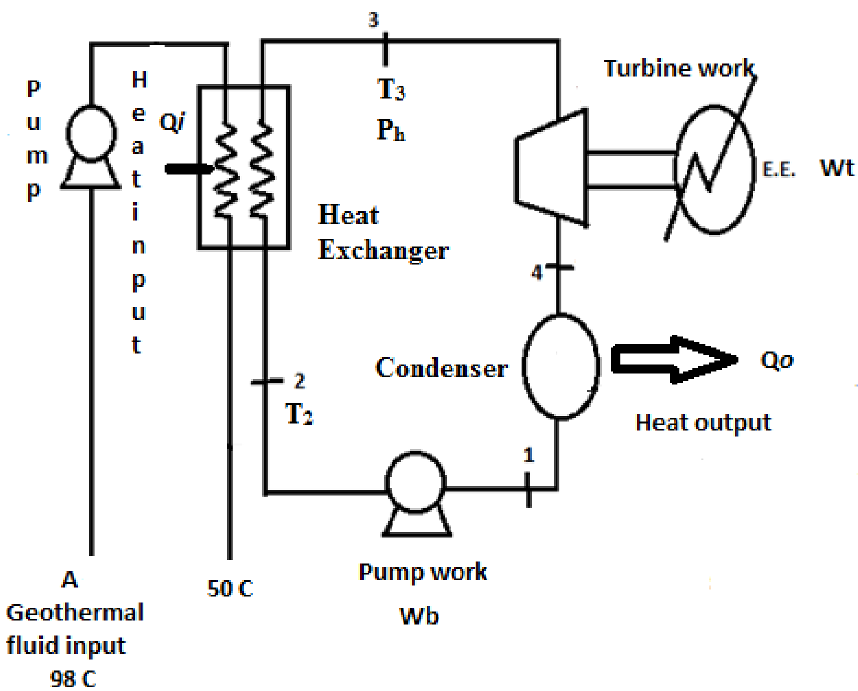

Figure 3. Process flow diagram of the thermodynamic cycle proposed.

State A (geothermal fluid inlet to the heat exchanger)

tAent: 98°C

tAsal: 50°C

hAent: 410.60 kJ/kg

hAsal: 209.32 kJ/kg

The water temperature geothermal reservoir to the inlet of the heat exchanger is 98°C and 50°C at the exit; the effectiveness (ε) exchanger considered for this case is 0.86

State 1 (condenser outlet and pump inlet)

t1=-57.34

p1=.5 bar

h1=-38.48 kJ/kg

s1=-.1714 kJ/kg-K

The low pressure cycle proposed is 0.5 bar pressure. The temperature is very low at this point but this because the working fluid (propane) is a refrigerant.

State 2 (pump outlet and inlet to the heat exchanger)

t2=-56.23

p2=p3

h2=-39.52 kJ/kg

s2=s1

In this part of the cycle, the pressure equals to state 3 as it is an addition of heat at constant pressure.

State 3 (turbine inlet)

t3= 88°C

p3=23.3 bar

h3=585.24 kJ/kg

s3=s4

In this state, the temperature of the working fluid (propane) increases in the heat exchanger. The pressure is determined by thermodynamic tables taking the temperature as reference.

State 4 (turbine exit and entrance to the damning)

t4=-57.34

p4=.5 bar

h4=402.38

s4=1.87 kJ/kg-k

For state 4 the pressure is the same as for state 1, since it is a rejection of heat at constant pressure.

To calculate the mass flow of working fluid (propane), a consideration is taken into account that the the power of the turbine set in 30 kW which is the minimum power required by C.F.E. for a small independent producer, and is calculated with the following formula [15]:

$$\dot{m}_{wf} = \frac{Wt}{\Delta hpro} Equation\ 5$$

$$\dot{m}_{wf} = \frac{30\ kJ/s}{182.86\ kJ/kg} = 0.16\ Kg/s$$

To determine the mass flow of geothermal fluid, mass and energy balance in the heat exchanger is performed, the formula is as follows:

$$\dot{m}_{gf} = \frac{\dot{m}_{res}(\Delta hpro)}{\varepsilon(\Delta hA)} Equation\ 6$$

$$\dot{m}_{gf} = \frac{0.16\ Kg/s(182.86\ kJ/kg)}{0.86\ (201.28\ kj/kg)} = 0.17\ Kg/S$$

The calculus of the cycle efficiency is as indicated below:

$$\eta = \frac{Pot}{\dot{m}_{res}(\Delta hA)} Equation\ 7$$

$$\eta = \frac{30\ kJ/s}{0.17\ kg/s\ (201.28\ kJ/kg)} = 87.67\ \%$$

3. Results

Results of thermodynamic design for the proposed binary power cycle are

tAent: 98°C
tAsal: 50°C
hAent: 410.60 kJ/kg
hAsal: 209.32 kJ/kg

t1=-57.34
p1= 0.5 bar
h1=-38.48 kJ/kg
s1=-0.1714 kJ/kg-K

t2=-56.23
p2=p3
h2=-39.52 kJ/kg
s2=s1

t3= 88°C
p3=23.3 bar
h3=585.24 kJ/kg
s3=s4

$\dot{m}_{wf} = 0.16\ kg/s$
Wt= 30kJ/s
η=87.67 %
$\dot{m}_{gf} = 0.17\ kg/s$

t4=-57.34
p4= 0.5 bar
h4=402.38
s4=1.87 kJ/kg-k

To determine hidrogeochemical characteristics of geothermal fluids, data from Table 2 are analyzed, based on the relative contents of Mg^{++}, Na^{+}, Ca^{++} cations.

Table 2. Cation concentration in samples from wells and springs hydrothermal from Ixtlán of Hervores.

Average relative concentration in mg/L			
Cation	Ca^{++}	Mg^{++}	Na^{+}
Concentration in mg/L	15	1.8	438
Fraction	15/454.8	1.8/454.8	438/454.8
%	3.29	.39	96

The relative contents of Mg, Na, Ca, analyze based on chart diagram Giggenbach cations (Figure 4) are as follows:

Cations Na^{+}

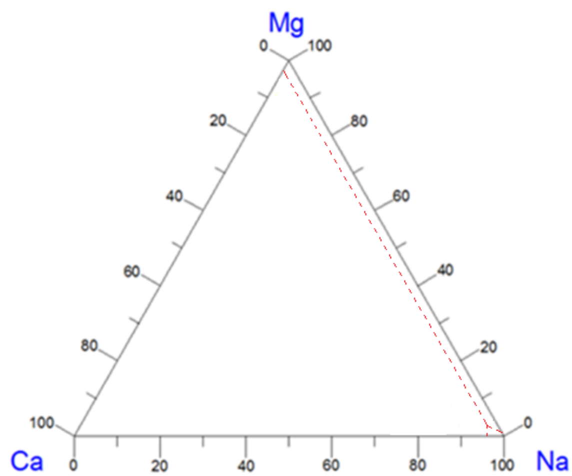

Figure 4. Cations Giggenbach Diagram of the Ixtlán geothermal reservoir.

4. Discussion

In the diagram Giggenbach, the highest concentration of cations is housed in the area of Na + (sodium). This indicates the presence of very soluble minerals so the Hydrogeochemistry of these springs, located as water soft type, unlike heavy or hard water containing a high amount of minerals of magnesium and calcium, and is also you called water hardness, hardness is the sum of the concentrations of metal cations other than alkali metal and hydrogen ion. In soft wáter maximum amounts dissolved are sodium salts [16].

The type of soft water is used in plants producing electricity, since by its low content of insoluble salts prevents the accumulation of sediment in pipes and precipitation of minerals, causing the locking thereof. The proposed binary cycle has an efficiency of 87.67%.

The inlet temperature to thermodynamic cycle considered for the geothermal fluid is 98°C, which is the boiling point of water at the height above sea level of the geothermal area with which the electrical power that can be generated is 347 kW, which represents a generation of 3.03 GWh / year.

5. Conclusion

Ixtlán de los Hervores geothermal area belong to the Mexican Volcanic Belt, is listed as a probable reserve of geothermal energy, with an estimated potential of 15 MW to be harnessed in electricity generation by middle of a geothermal binary plant, can also be used, being an agricultural area, for drying seed and food dehydration or as a tourist area, which is already in operation due to the hot springs.

In assessing the characteristics of geothermal fluids of the area by Giggenbach diagrams, indicate them as a high concentration of sodium cation (Na +) which indicates that it is soft type water, so it has a content of very soluble minerals and is recommended for use in power generation.

For the binary thermodynamic power cycle proposed at reservoir conditions studied, an ideal theoretical efficiency equal to 87.67% was calculated, which is an very acceptable value.

6. Conflict of Interest

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

7. Acknowledgment

NA

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