

# PROPOSAL FOR A GEOTHERMAL COGENERATION PLANT IN CÓSALA, 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.

On the other hand, cogeneration is the simultaneous use of the same primary energy source for two uses such as electricity generation and use of waste heat in an industrial process, services or housing. In a geothermal zone this refers to the use of the brine and / or geothermal steam for direct use and power generation otherwise.

In this work is proposed a geothermal cogeneration cycle to better use of geothermal resources available in San Juan Cosala, Jalisco. Whereby is possible obtain up to 13.2426 KWh of electricity generation and 560.35 KWh for direct use in balneology or equipping industrial facilities and housing services.

## Keywords

Geothermal cogeneration plant Proposal

## 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 [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 both mineral deposits and geothermal resources [5], reason by wich is convenient a study of regional geothermal prospecting.

## 1.2 Hydrothermal Activity Area

The regional geothermics consists 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 (Villamar) [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 ( $^{18}O$ ) 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.

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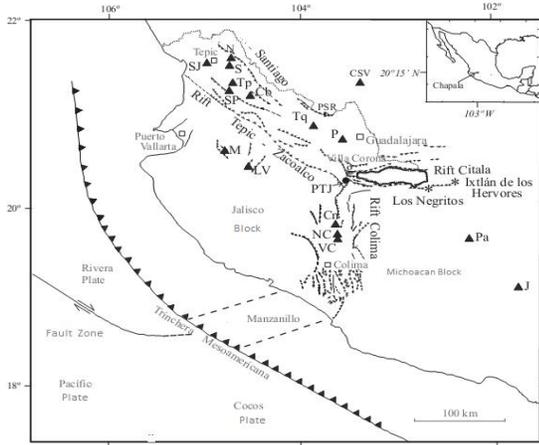


Figure 1: Regional Geological Map

## 1.3 TYPES OF GEOTHERMAL MANIFESTATIONS

Generally, geothermal reservoirs are not closed systems, so there are surface discharges as springs, fumaroles, steaming pits or acidic soils. Springs usually categorize as: mild, 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].

## 2. BASIC ENGINEERING OR THERMODYNAMIC DESIGN OF THE COGENERATION CYCLE

For the geothermal area of San Juan Cosala, is proposed a Rankine Cycle Ideal plant for generating of electricity, as well as for use in heating and / or cooling, to adequately exploit the geothermal resource through a thermodynamic cycle cogeneration as shown in Figure 2.

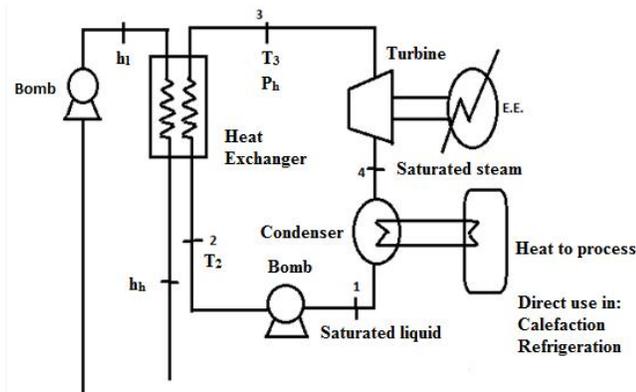


Figure 2: Flow diagram of cogeneration cycle process.

- 1-2.- isentropic expansion in the turbine.
- 2-3.- transfer heat at constant pressure in an ideal cycle.
- 3-4.- isentropic compression pump.
- 4-1.- Adding heat at constant pressure under ideal conditions.

Figure 3 shows the TS diagram of the cogeneration system

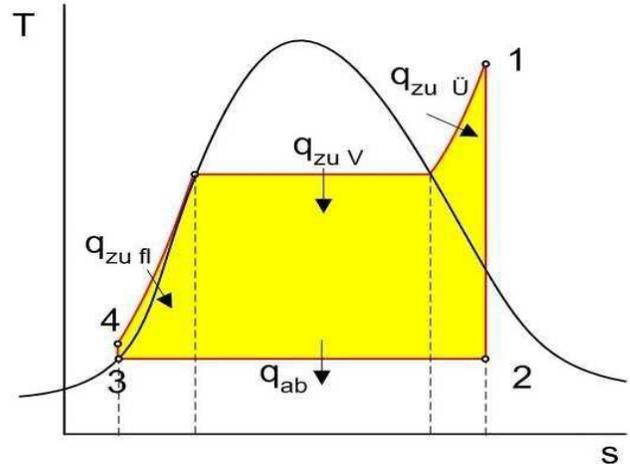


Figure 4: Diagram of the cogeneration system TS [12].

The coolant enters the pump as saturated liquid and is compressed into isentropic until the operating pressure of the heat exchanger. Fluid temperature increases during this process due to decreased specific volume of fluid. The fluid enters the heat exchanger as a compressed liquid and leaves the heat exchanger as superheated steam. The heat exchanger heat is transferred to the coolant which essentially constant pressure. The superheated steam enters the turbine where it is expanded isentropically and work to turn the shaft that is connected to the electric generator occurs. The pressure and the steam temperature decreases in this process until the values in the state 4 to enter the condenser. The vapor condenses at a constant pressure, leaving the condenser as saturated liquid and returns to the pump to cycle [12].

## 2.1 Elements of Cogeneration Cycle and Its Mathematical Expressions

Cogeneration is defined as the sequential production of electrical and / or mechanical energy and usable thermal energy for industrial and commercial processes from a single source of primary energy (fuel) [12].

Cogeneration can be evaluated by the equation:

$$\eta = \frac{\text{Output Net Work} + \text{Process Heat Delivered}}{\text{Total Heat Input}} = \frac{W_{net} + Q_p}{Q_{input}} \quad (1)$$

or

$$\eta = 1 - \frac{Q_{waste}}{Q_{input}} \quad (2)$$

Where

$\eta$  = Efficiency

$Q_{waste}$  = Represents the heat exchanged in the condenser

$Q_{input}$  = Heat input

Heat Exchanger: is the device in Which heat from geothermal fluid is transferred to the fluid of work in order to complete the cycle

$$\frac{Q_{input}}{\dot{m}} = h_3 - h_2 \quad (3)$$

Where

$\dot{m}$  = Mass flow

$Q_{input}$  = Heat input

$h_3$  and  $h_2$  enthalpies in points 3 and 2.

Turbine: In this equipment the work fluid expands in isentropic way and produces work, by rotating the shaft of the electric generator without loss of heat to the environment

$$\frac{W_t}{\dot{m}} = h_3 - h_4 \quad (4)$$

Where

$W_t$  = Turbine work

$h_3$  and  $h_4$  enthalpies in points 4 and 3.

Condenser: This device transfers energy to a fluid of work of a conditioning system that can be heating, cooling or both. This is responsible for condensing the high quality fluid, functions as a heat exchanger transferring heat surplus of working fluid to a system of additional utilization, part of the cycle and cogeneration.

$$\frac{Q_p}{\dot{m}} = h_4 - h_1 \quad (5)$$

Where

$Q_p$  = Heat transferred from of working fluid to a system of additional utilization,

$\dot{m}$  = Mass flow of working fluid

$h_4$  and  $h_1$  enthalpies in points 4 and 1.

Pump: This is the device that increases the kinetic energy of the fluid passing therethrough. The pump is assumed isentropic and heat transfer outwardly zero

$$\frac{W_b}{\dot{m}} = h_2 - h_1 \quad (6)$$

Where

$W_b$  = pump work

$\dot{m}$  = Mass flow of working fluid

$h_2$  and  $h_1$  enthalpies in points 2 and 1.

### 3. COGENERATION SYSTEM ANALYSIS

#### 3.1 Considering n-Propane as Fluid of Work for the Cogeneration System

Heat transferred from geothermal fluid to cogeneration cycle

$$Q_{Geothermal\ fluid} = m_{Geothermal\ fluid} C_p_{Geothermal\ fluid} \Delta T_{Geothermal\ fluid}$$

Where

$$C_p_{Geothermal\ fluid} \approx C_p_{water} = 4.1813 \text{ KJ/Kg } \text{ } ^\circ\text{C}$$

$$m_{Geothermal\ fluid} = 1 \text{ Kg/S} \quad (\text{for an unitary analysis})$$

$$\Delta T_{Geothermal\ fluid} = (95-55)^\circ\text{C}$$

$$Q_{Geothermal\ fluid} = (1 \text{ Kg/S})(4.1813 \text{ KJ/Kg } \text{ } ^\circ\text{C})(95 - 55)^\circ\text{C} = 167.252 \text{ KJ/S}$$

Efficiency of the heat exchanger =  $\epsilon \cong 0.86$

$$Q_{input} = Q_{Geothermal\ fluid} * \epsilon = 167.252 \text{ KJ/S} * 0.86 = 143.83672 \text{ KJ/S}$$

**Analysis of state 2** (considering ideal Rankine cycle)

$$P_2 = 3,92 \text{ Kg/cm}^2$$

$$T_2 = 50 \text{ } ^\circ\text{C}$$

$$h_2 = \text{ENTHALP}$$

$$Y(\text{Propane})$$

$$T = T_2; P = P_2$$

$$= 568.9 \text{ kJ/kg}$$

$$s_2 = \text{ENTROP}$$

$$Y(\text{Propane}; T = T_2; P = P_2)$$

$$) = 2.116 \text{ kJ/kg } \text{ } ^\circ\text{K}$$

**Analysis of state 3**

$$P_1 = P_2$$

$$T_3 = 85 \text{ } ^\circ\text{C}$$

$$h_3 = \text{ENTHALPY}(\text{Propane}; T = T_3; P = P_3) = 636.4 \text{ kJ/kg}$$

$$s_3 = \text{ENTROPY}(\text{Propane}; T = T_3; P = P_3) = 2.314 \text{ kJ/kg } \text{ } ^\circ\text{K}$$

**Flow mass of n-propane**

$$QCA = p * \Delta hp$$

$$QCA = 719,2 \text{ KW}$$

$$Ahp = (h_3 - h_2)$$

$$m_{propane} = \frac{Q_{input}}{\Delta h_{propane}} = \frac{Q_{input}}{h_3 - h_2} = \frac{143.83672 \text{ KJ/S}}{(636.4 - 568.9) \text{ kJ/kg } \text{ } ^\circ\text{K}} = 2.1309 \text{ Kg/S}$$

**Analysis of state 4**

$$S_4 = S_3$$

$$P_4 = 1.5 \text{ Kg/cm}^2$$

$$h_4 = \text{ENTHALPY}(\text{Propane}; S = S_4; P = P_4) = 576.1 \text{ kJ/kg}$$

$$t_4 = \text{TEMPERATURE}(\text{Propane}; S = S_4; P = P_4) = 50.89^\circ\text{C}$$

**Analysis of state 1**

$$S_1 = s_2$$

$$h_1 = 15,75 \text{ KJ/Kg}$$

$$s_1 = 0.066 \text{ KJ/Kg } \text{ } ^\circ\text{K}$$

**Analysis of state 2'** (correction to real Rankine cycle)

$$P_2 = 3.92 \text{ Kg/cm}^2$$

$$s_2 = s_1$$

$$h_2' = \text{ENTHALPY}(\text{Propane}; s = s_2'; P = P_2') = 16.14 \text{ kJ/kg}$$

$$t_2' = \text{TEMPERATURE}(\text{Propane}; s = s_2'; P = P_2') = 33.3^\circ\text{C}$$

**Flow mass of n-propane with the h2'**

$$m_{propane} = \frac{Q_{input}}{\Delta h_{propane}} = \frac{Q_{input}}{h_3 - h_2'} = \frac{143.83672 \text{ KJ/S}}{(636.4 - 16.14) \text{ kJ/kg } \text{ } ^\circ\text{K}} = 0.2318 \text{ Kg/S}$$

[12]

### 4. RESULTS

The results obtained when calculating the thermodynamic system described are as follows:

**Gross Power**

$$W_{net} = \text{Gross Power} = m_{propane} * (h_3 - h_4) = 0.2318 \frac{\text{Kg}}{\text{S}} * \frac{(636.4 - 576.1) \text{ kJ}}{\text{kg}} = 13.9775 \text{ KJ/S}$$

**Net power or mechanical power**

$$\text{Net power} = m_{propane} * [(h_3 - h_4) - (h_2 - h_1)] \\ = 0.2318 \frac{\text{Kg}}{\text{S}} \left[ (636 - 576.1) - \frac{(16.14 - 15.75) \text{ kJ}}{\text{kg}} \right] = 13.7944 \text{ KJ/S}$$

**Electric power**

$$\text{Electric power} = \eta_{\text{generator}} * \text{Net power} = 96\% * \text{Net power} \\ = 13.7944 \text{ KJ/S} * 0.96 = 13.2426 \text{ KJ/S}$$

In an hour 13.2426 KWh

In a day 317.8233 KWh/day

In a year 116,005.5376 KWh/year

[12]

#### 4.1 Discussion of Results

For the proposed cycle cogeneration, its design, gave a result of 13.2426 KWh electric power, so this cogeneration plant for power generation and direct use in Cósala, Jal is feasible. Whereupon it would produce 317.8233 KWh / day, in one year it would produce 116,005.5376 KWh / year.

The power output of a 13.2426 KWh of electricity generation and 560.35 KWh for conditioning for both heating and cooling.

#### 5. CONCLUSIONS

The geothermal area of San Juan Cosala located within the Volcanic Belt, possesses appropriate characteristics to be exploited in the production of electricity and direct use of geothermal resource.

The proposed cogeneration system for electricity production and conditioning in San Juan Cosala, allow better use of the geothermal resource that also has use in balneology, that is given now.

This type of cogeneration system is feasible application in geothermal reservoirs, which can be used in heating and cooling hotels and / or resorts as well as for power generation and other direct uses.

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