BINARY CYCLE: POTENTIAL EXPLOITATION OF THE RESIDUAL BRINE AT CERRO PRIETO

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ABSTRACT

In this work a brief review of the state of the art on the generation of electricity utilizing binary cycle geothermal plants is carried out. A description is made of the most important characte ristics of several binary plants located in the geothermal area of the State of California, U.S.A., neighbouring the Mexicali Valley, rich in geother mal resources as well. Thus, the potential use of the geothermal reservoirs of Mexico, and in parti cular of Cerro Prieto can be considered with two perspectives in mind: a)-The use of a formidable amount of residual brine actually being produced in the geothermal works, the biggest of Latin Ame rica, utilizing the binary cycle system, and b)-The increase of the generation of electric po wer in the state of Baja California, Mexico.

INTRODUCTION

The utilization of geothermal resources of low and medium enthalpy (90-170 °C) for direct uses (1) can be applied to the generation of electrici ty making use of the binary cycle technology. The latter implies an effective method to extract ener gy from geothermal fluids at temperatures relati vely low, transfering heat to an organic fluid and utilizing this vapor to produce electric power. This process is known as Organic Rankine Cycle (ORC) or else as Binary Cycle. The terminology may be applied more extensively to any kind of process which involves the transference of heat from the geothermal fluid to an organic working fluid across an interface such as a heat exchanger.

A research work (2) concluded that the low en thalpy to high enthalpy energy resource rate in Mexico is 3.7, which shows the availability of this resource and the possibility of utilizing bina ry cycle plants amongst other alternatives, taking adventage integrally of the energy contained in the geothermal reservoirs and in the residual brines disposed of, in the simple or double sepa ration geothermoelectrical plants in the case of Cerro Prieto, Mexicali, Mexico.

A study (3) carried out in 1982 on this type of hydrothermal resource, concluded that in the cen ter and southern areas of Mexico, there is a pro ven potential of 36000 TMW (Thermal Mega Watts) and in the northern areas, located mainly at the Mexicali Valley, Laguna Salada and Altar Desert, it amounts to 11900 TMW (such calculations are pre- dictions for the next 30 years). This rounds up a total potential of 47900 TMW for all the country in low enthalpy reservoirs, against a potential of 29300 TMW for high enthalpy reservoirs (12000 TMW for Baja California, 2700 TMW in Jalisco, 6000 TMW at Los Azufres, Michoacan, and close to 100 thermal sources of aproximately 85 TMW, each one of them pinpointed in the center and southern areas of Mexico).

FUNDAMENTAL FACTOR OF INFLUENCE IN THE CONSUMPTI ON OF ELECTRIC ENERGY IN THE VALLEY OF MEXICALI.

The state of Baja California, Located in the north-west of the country, and in particular the valley of Mexicali, has a dry and hot climate with 18 rainy days in the city and only 10 rainy days in the rural areas (4) with the rest of the days of the year of intense sunshine. Its annual average dry bulb temperature is 23°C and reaches ocassionally room temperatures higher than 50°C during the hot summer. Out of four main cities in Baja California, the city of Mexicali has the main consumption of electricity for the conditio- ning of livins spaces, given its geographical situation and climatology.

In addition to what has been said, it is nece ssary to add the great industrial growth of Mexi cali during recent years, such that it has been ranked as one of the industrial cities of the fu ture in the north-west of Mexico, together with Tijuana. Therefore the growing demand of electri city supply is a problem to cope with in years to come.

Finally, electricity may be produced for expor tation purposes, as it has been carried out up to now with the total production from Cerro Prie to II and III, at Mexicali, B.C., bringing (5) into the country an average of 70 million Ameri can dollars per year.

DESCRIPTION OF THE BINARY CYCLE PROCESS

The principle of binary cycles utilizing the geothermal energy, resides on absorbing the heat contained in the fluid, by a substance with a boiling point far below the temperature of the geothermal fluid, such that there is a heat trans fer towards the organic working fluid which will evaporate and expand in a conventional turbine.

In the geothermal binary cycle, Fig. 1, the geo thermal fluid from the production wells is passed through a heat exchanger to increase the temperatu re of the pressurized liquid phase of the working fluid, converting it to the high enthalpy gaseous phase. The gas thus obtained is expanded in a tur bine for the generation of work, converting this fluid to the lower enthalpy gaseous phase.

On the other hand, the geothermal fluid used is returned to the reservoir using reinjection wells. As a result a closed cycle is established, whereby the heating and working fluid do not come in con tact with the environment.

The low pressure vapor at the turbine exit is cooled and condensed utilizing a heat exchanger with cooling water as the cooler. The condensate of the liquid fluid is later pump to the brine evaporator at high pressure, thus closing the cy cle.

Working fluids

There are a big number of possible working fluids that may be used in the binary cycle: all of them have different thermodynamical properties which make them suitable for this kind of work. In general, an efficient working fluid should ha ve the following characteristics:

1- A critical temperature far below the maximum temperature that can be reached in the cycle, which is fixed by the properties of the materials used in the process. This makes possible to evapo rate the fluid and add a considerable amount of heat at the maximum temperature.

2- Saturation pressures at maximum and minimum temperatures within a given range, neither invol ving high pressures as to cause strength of mate rial problems, nor low pressures as to give raise to sealing problems against atmospheric infiltra tions.

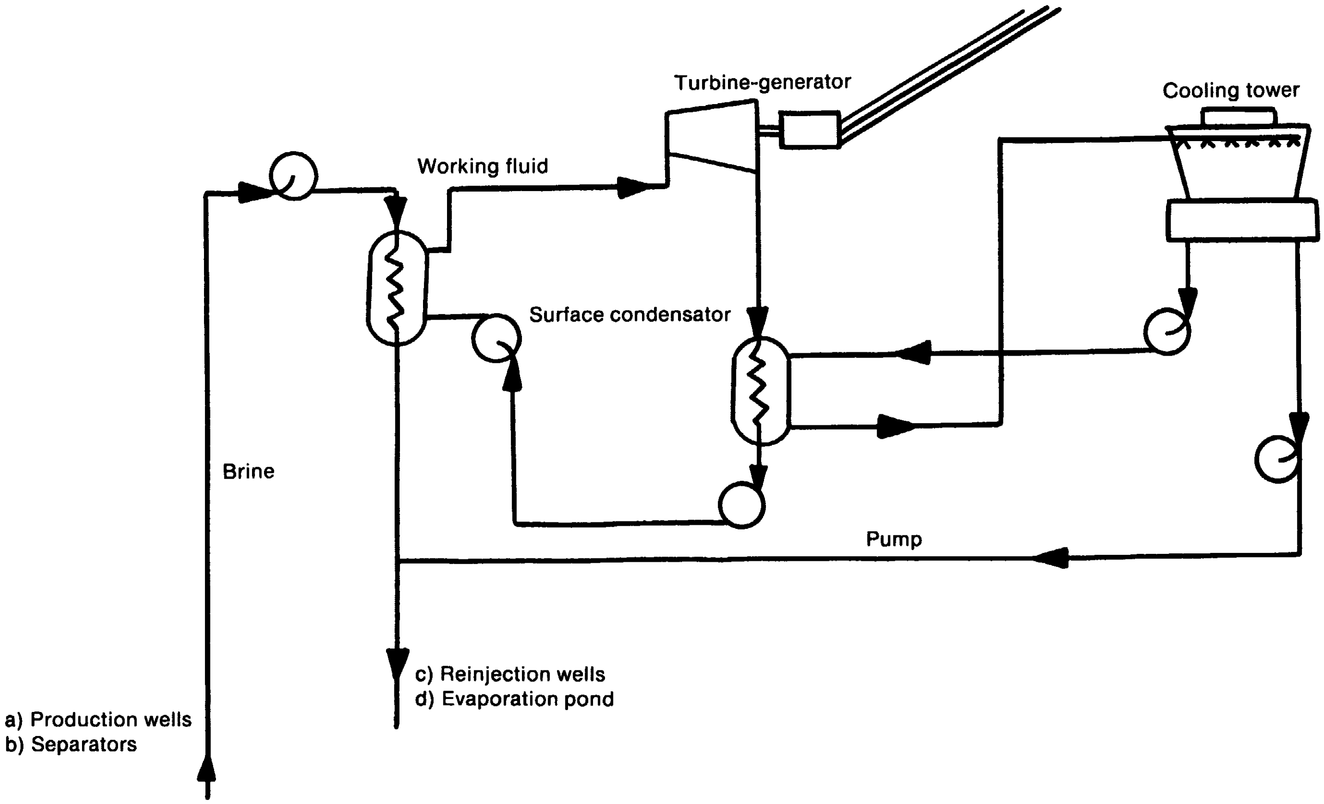

Fig. 1 Schematic diagram of a binary cycle. a) and c) conventional binary practice, b) and d) an alternative at Cerro Prieto.

3- Chemical stability and inert during temperature changes in the cycle.

4- Vapor saturation line proximately close to tur bine expansion line. This will avoid excessive humi dity at the turbine exit to eliminate preheating, and also will allow that all or nearly all of the heat rejection, to take place at the minimum tem perature.

5- Unexpensive and not difficult to find.

6- Not toxic.

Finding a substance with all the advantageous properties and no undesirable is impossible. Due to this limitation, a selection of the existing fluids should be done according to the objectives and the priorities assigned to each property. As an option, searching for the right decision, the utilization of a mixture of fluids is highly reco mmended.

Heat exchangers in the binary cycle

The heat exchanger may be considered the most important component in the binary cycle applied to geothermal fluids. Keeping the heat transfer surfa ces clean is vital for an effective operation, as the accumulation of any substance diminishes consi derably the performance of the equipment. The imme- diate result of the dirt or scaling of the surfa ces is that for a temperature differential (ΔT) between the fluids the heat rate is reduced. It will be required to increase (ΔT) to keep the heat rate constant, thus the available energy of the system is lowered and consequently the effi ciency diminished too. Therefore it is a must to keep the heat transfer surfaces clean.

The current technology of design and fabrication of heat exchangers is very advanced, and if it is applied properly, it will be suitable to fulfilled the demands of geothermal binary cycle technology. The conventional heat exchanger, tube and shell type is the more practical by its simplicity and ease of operation and less expensive to make, than the special design type.

At the present time the fluidized bed heat ex changers are in a design stage at the Instituto de Investigaciones Electricas, at Cuernavaca, More los, Mexico (6).

Binary vs. double flash steam

There are many alternatives to take advantage of the geothermal energy using the binary cycles. The geothermal fluids from hot water wells can be used in either phase, liquid o vapor, separately, as it is not practical utilize them in a mixture. In general it is desirable to work with the li- quid phase, allowing the use of reduced size heat exchangers, whether with separated liquid or with pressurized fluid with a down hole pump.

It is interesting to observe (7,8) that the exploitation of the geothermal energy in the form of a separated brine is more efficient when it is utilized in a binary cycle, rather than using it in a double flash steam (Fig. 2). In the former 8.3% utilization efficiency is obtained in comparison to 5.45% in the double flash steam.

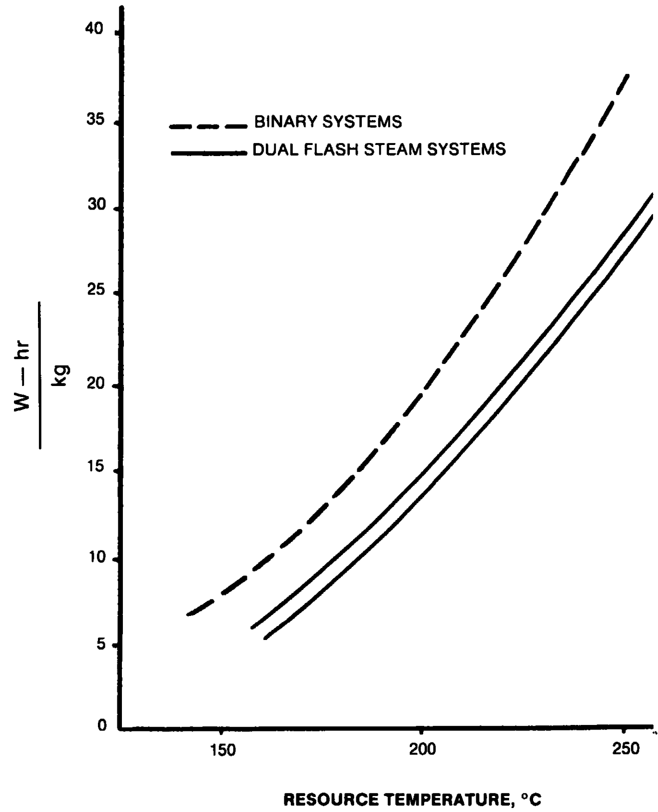

Fig. 2 Net geothermal brine effectiveness.

BINARY PLANTS IN OPERATION

According to Dr. Axtman (9) up to 1977 the efficiency of the binary cycle had not been demos trated. Today, in the 80's, there are real cases of construction and operation of binary plants in the U.S.A. As follows, a reference is made of the more relevant binary plants established in Impe- rial Valley contiguous to the geothermal area of Cerro Prieto, in Mexicali, Baja California:

a)- Magmamax Binary Geothermal Plant at East Mesa, California, U.S.A., Cap. 12.5 MW

When it was completed in 1979, it was the first (10) commercial plant of its class in the

U.S.A. One important characteristic to be mentioned: that it utilizes an aspersion cooling system instead of a conventional cooling tower.

b)-Heber Binary Plant, Imperial Valley, California, U.S.A., Cap. 70 MW

Initially, the objectives of this plant (11) were to demostrate the potentiality of geothermal energy at moderate temperatures (below 210 °C) to produce electric energy economically, with the binary cycle technology and establish a programme cost, equipment and reservoir performance and the environmental acceptability of this kind of plant. The working fluid is made of a mixture of 90% isobutane and 10% isopentane. During the first years of operation there were some technical problems (12) that had to be overcome: with the pumping system of the working fluid condensate and control valves of the turbine, amongst others. At the moment it is out of operation.

c)- Ormat I, Modular Binary Plant, East Mesa, California, U.S.A., Cap. 32.5 MW.

This plant (13) consists of 26 Ormat energy converters modules, 1.25 MW capacity each. An innovative principle is used in the configuration of 26 modules to maximize the total efficiency of the generating plant. With the cascading principle in mind, if one module of the plant is close down for maintenance, the rest of the modules will use nearly all of the geothermal fluid to operate at higher levels of production as the generators are overdesigned. Consequently, the total capacity can be maintained during major overhaul in some modules. The working fluid is isopentane.

Chemical composition of the brines used at binary plants in California.

The brines utilized in the Binary Plants installed in the neighbouring state of California, are usually of medium content in total dissolved solids (TDS). Although it has been difficult to locate published data (14) on the brine composition for each geothermal field in particular, as there is some reserve on its diffusion, by personal communication (15) it is known that the brine composition for Ormat I binary Plant falls in the range of 17000 ppm in TDS. This value drops to 10000 ppm in TDS for the brine utilized in the Heber binary plant (16) in California.

BINARY CYCLE IN MEXICO

Some experiments have been carried out (6) with a pair of ORC units at Los Azufres, Michoacan, utilizing low pressure vapor as much as residual brine. A unit is 10 KWe capacity, uses refrigerant R12 as a working fluid and residual brine as a primary fluid. The second unit in operation is 50 KWe capacity and the refrigerant R113 works as the secondary fluid.

The operation of the latter was carried out with separated vapor and later it was thought to operate it with residual brine. The main problem faced by the project had to do with scaling of the heat exchanger. To cope with it, experiments on fluidized bed were performed and later with direct contact heat exchangers.

One of the ORC units had in general a good performance, but as the instrumentation was badly affected by the extreme corrosive atmosphere, it was only operated by a total of 830 hours for about a three year period. Thus it may be said that the technology for the exploitation of medium and high enthalpy geothermal fluids has been somehow studied in Mexico. On the contrary the experimentation with low enthalpy fluids is under perspective.

At the recent meeting at Mexicali. B. C., Mexico, it was mentioned that CFE (Com. Fed. de Elect.) was interested in using (5) this binary cycle technology, once it becomes economically competitive against other geothermal processes.

Quantity and TDS of the residual brine at Cerro Prieto.

At Cerro Prieto I, 81% of the separated brine from 34 production wells is sent to the double flash steam plant for the generation of medium and low pressure vapor for its utilization in Unit 5 (30 MW capacity). At Cerro Prieto II and III residual brine is obtained after a double separation, being sent to the drainage canal afterwards. The TDS content of the separated brine at Cerro Prieto varies from well to well. An average of 25000 ppm of TDS can be considered representative (17).

At the present moment the geothermoelectric's capacity at Cerro Prieto is 620 MWe. During total production there will be 12000 ton/hr discharge of residual brine sending a portion of it to the evaporation pond (3729 ton/hr) after extracting part of its energy in the double flash steam separators and directly to the evaporation pond, the remainder.

The temperature range of the residual brine is 120-160 °C at the separators at Cerro Prieto, which represents a considerable amount of usable energy. In the Binary Cycle technology, low enthalpy geothermal fluids may be used in a 90 150 °C temperature range, which frames Cerro Prieto's residual brine in a favourable condition for exploitation.

During a preliminary geothermal energy evaluation at Cerro Prieto (18) in Mexicali, it was concluded that there is an expected generation capacity of 14317 MWe for 30 years of exploitation of the reservoir.

DISCUSSION AND CONCLUSIONS:

At present, Mexico counts with its own

technology for the production of electric energy using high enthalpy geothermal resources at Cerro Prieto, Mexicali, Baja California, Los Azufres, Michoacan and other potential geothermal reservoirs. However, this is not applied to the utilization of low and medium enthalpy geothermal resources.

In other countries such as U.S.A. and Israel, these resources have been exploited efficiently using the binary cycle process with very interesting results (there are several plants at full operation in the neighbouring state of California, U.S.A.). In Mexico, up to date some attempts have been made at Los Azufres, Michoacan with prototypes that have demostrated incipiently its future exploitation once some difficulties on the handling of the primary fluid are mastered.

Taking into consideration the great amount of geothermal reserves of low and medium enthalpy already evaluated in existence in the various explored reservoirs in Mexico, amongst them the most important Cerro Prieto and considering that it is possible to bank on four of the most important parameters to support the installation of a binary plant, which are:

a)- A useful brine temperature.

b)- The chemical thermodynamical properties of the brine makes possible its use as a primary fluid under suitable pressure and temperature conditions.

c)- Proven existence of the geothermal resource in the long term.

d)- Local electric energy demand in the state of Baja California, and external demand for exportation.

Therefore it is recommended the feasibility of a binary plant of a given capacity for the best optimal exploitation of the residual energy contained in the separated brine at Cerro Prieto for the following reasons:

I- There is a reduced contact of the residual brine with the environment when reinjection is practiced (Fig. 1, c).

II- The efficiency of a binary plant is slightly better than a double flash steam, with a 2.05% more of utilization efficiency.

III- Possibility of exploiting the energy available in the brine after the separation of the liquid-vapor mixture at the separator: the vapor being sent to the turbine.

IV- Increase the percentage of electric generation from geothermal resources in Mexico (0.2% of the total at the present time) as compared (19) to other traditional energy sources.

V- Considering the quantity of residual brine produced in Cerro Prieto I, II and III, the temperature of the resource and taking into account its total utilization, it may be thought of a total of a series of binary plants of a 240 MWe maximun capacity (which means a 40% increase of the current installed capacity).

VI- Feasibility of utilizing the infra-structure already installed in the geothermal works, putting aside the initial investment which constitutes a heavy cost in geothermal projects.

VII- Alternative generation of electricity to support the industrial development of the state and exportation of electric energy to U.S.A. to inject dollars in the economy of the country.

What is left is to study the technology already developed on the existing binary cycle and adapt it to the regional conditions of Mexico, so that it may work as a supplement to the actual geothermal processes now in operation. With this in mind efforts should be oriented towards the solution of what in Cerro Prieto may represent the main problem: the handling of the concentrated residual brine through pipes and heat exchangers by controlling the chemical thermodynamical properties to avoid precipitation, scaling and erosion.

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