MEXICAN EXPERIENCE IN GEOTHERMAL POWER GENERATION

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ABSTRACT

For the past 20 years, electricity from geothermal origin has been produced in the Cerro Prieto field and, more recently, in Los Azufres and Los Humeros. Backpressure, condensing and binary cycle units are installed in these fields, each type with its advantages and disodvantages. One of the main problems -- especially at the Los Humeros field -- is that of turbine scaling, wich has been faced successfully through a washing steam and turbine process.

INTRODUCTION

At the present, Mexico has an installed geothermal electrical capacity of 753 MW, from which 5877 GWh were generated in 1993. This permits Mexico, after 20 years of producing electricity through geothermics, to occupy second place in the world, behind only the U.S. Above and beyond this, they were able to obtain a plant factor rating of 91% allowing them to take over first position in the world in this category.

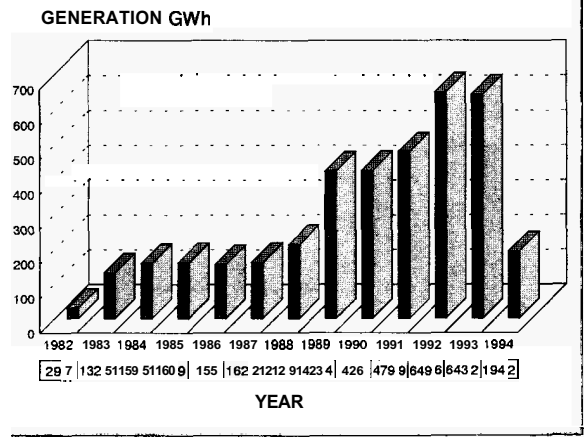
The 753 MW are distributed over three geothermal fields: Cerro Prieto, Los Azufres and Los Humeros. The field in Cerro Prieto carries the majority of the load with 620 MW being generated there from steam supplied by 130 wells, which produce water and steam with similar characteristics. The field in Los Azufres, Michoacan, generates 98 MW supplied by steam from 19 production wells and in Los Humeros, Puebla, the final 35 MW are generated from 17 wells. Figures 1, 2 and 3 demonstrate the generation of electricity in those fields over the last years.

Los Azufres and Los Humeros are both volcanic geothermal fields, but the chemical characteristics of their fluids (steam and water) vary considerably, not only between each other, but also between individual wells within the same field. The same result occurs when analyzing the gas content of the steam. Table 1 shows the average chemical composition of produced water in those fields, including Cerro Prieto.

Tabla 1.- *Average chemical composition of water in mg/l.*

FIELD	SiO_2	B	Cl	Na	K	Ca	HCO_3
LOS HUMEROS	620	1247	235	207	27	2	100
LOS AZUFRES	600	209	3011	1650	422	9	42
CERRO PRIETO	650	174	14200	7350	1520	528	11

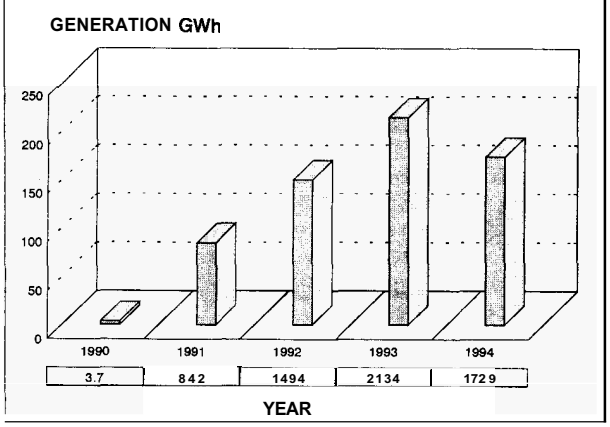
FIG.1.- GEOTHERMAL FIELD LOS AZUFRES GENERATION JULY 82 - APRIL 94



TYPES OF PLANTS

The exploitation of steam extracted from the Earth for electrical generation is carried out by gathering the steam and transporting it to power station. From it the maximum energy is efficiently removed using support equipment, such as direct contact or shell and tube condensers. This is done by means of systems that extract noncondensable gases or by using backpressure units with atmospheric discharge. Other means for taking advantage of geothermal resources include the employment of binary cycle units or the use of total flow turbines taking advantage of both water and steam.

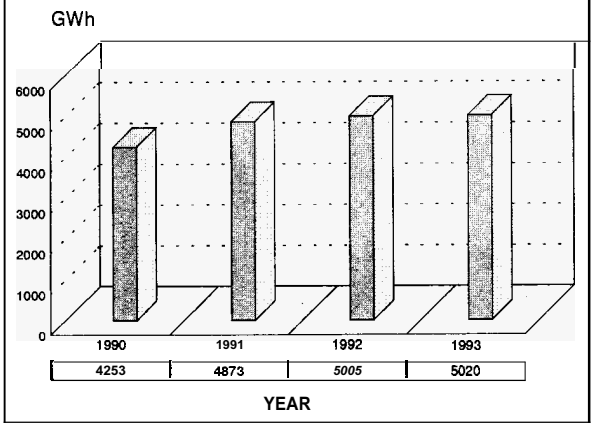
FIG.2.- GEOTHERMAL FIELD LOS HUMEROS GENERATION 1990-APRIL 94



In Cerro Prieto, in the area known as Cerro Prieto I (CP-I), there are four installed units, each 37.5 MW, that use barometric condensers, as well as a 30 MW unit, impulse and double flow reaction with direct contact condenser. In the sectors known as CP-II and CP-III, four other units of 110 MW each, using various types of condensers, are installed.

In these units, the steam enters the turbine and escapes by means of either direct contact or shell and tube stainless steel condensers. They require the employment of cooling water, condensing pumps, a cooling tower, compressors and ejectors for the extraction of noncondensable gases, hydrogen systems for cooling the generator and security and control circuits.

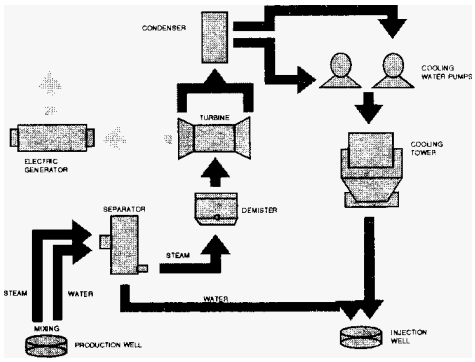
FIG. 3.- GEOTHERMAL FIELD CERRO PRIETO GENERATION 1990-1993



Usually, the steam arriving to this type of turbine contains 2 to 3% gases, in weight, of which 98% is CO_2 and H_2S making up the remaining. When direct contact condensers are used the majority of H_2S is diluted in the water and subsequently escapes through the cooling tower. Nonetheless, if shell and tube condensers are used there is not such dilution.

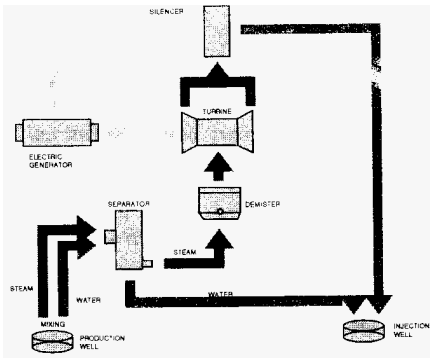
Due to the large number of control and operation systems, the type of units at Cerro Prieto demand a high initial investment but, in return, deliver a high thermal yield: average specific consumption of steam of Cerro Prieto plants is 9.4 tons per hour per MW. A typical performance chart of a condensation plant, such as those installed in CP-II and CP-III, is shown in Figure 4.

FIG 4.- SCHEMATIC FUNCTION OF A CONDENSIG TURBINE



In the Los Azufres field there are nine backpressure units of 5 MW each. In these units, the steam passes through the turbine and later discharges into the atmosphere. They use minimal installations and security systems as compared to a condensing plant, like those in Cerro Prieto. In the case of backpressure units, with atmospheric discharge, there is no requirement for a large initial investment but the yield is not as great as in a condensig unit because of a specific consumption of 12 th/MW. Figure 5 illustrates a typical performance scheme for a backpressure unit, like the nine installed in Los Azufres.

FIG 5.- SCHEMATIC FUNCTION OF A BACKPRESSURE TURBINE



When the first backpressure units were installed in Mexico, the CFE (Comisión Federal de Electricidad) -- the public entity responsible for generation, distribution and sale of electrical energy in Mexico -- established certain objectives, which were:

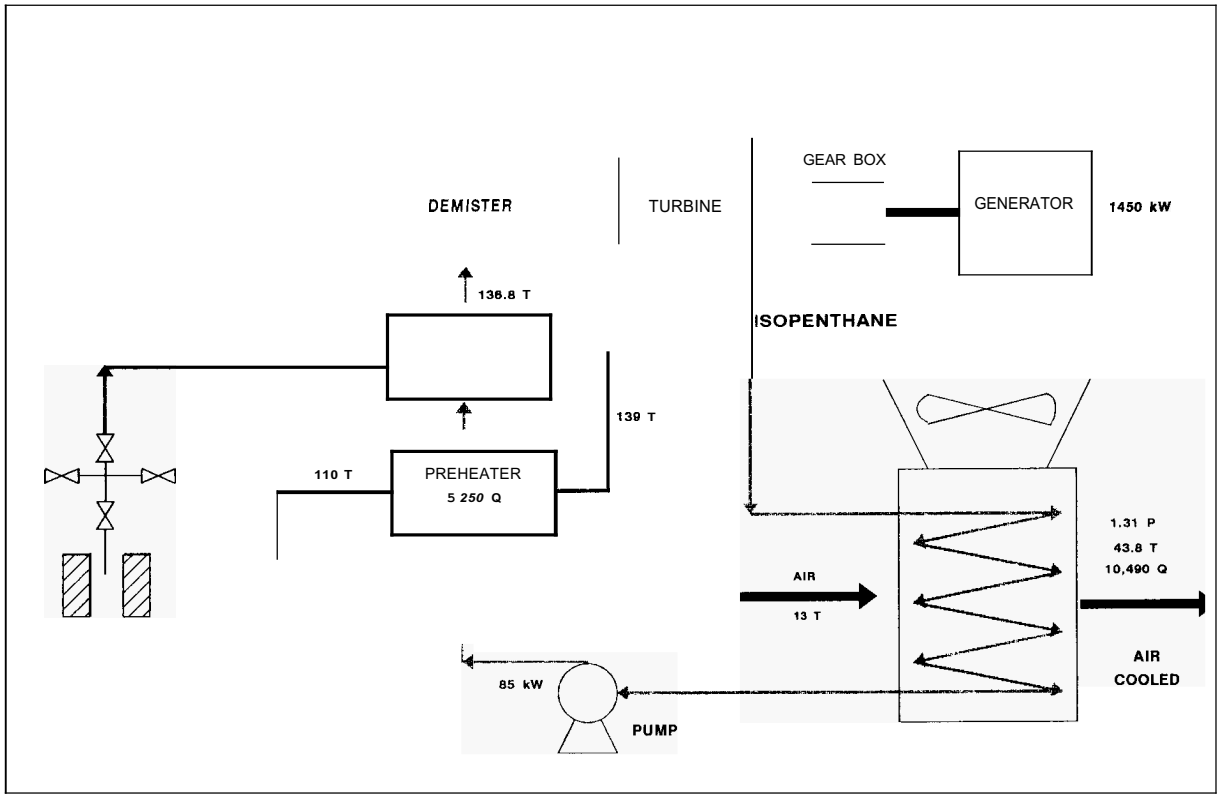
- Study the behavior of new reservoirs under continual exploitation.
- Possess the possibility of transferring the unit with the greatest degree of recovery of installations and equipment.
- Simplify installations and equipment.
- Reduce initial investment cost.

Besides the backpressure units, in Los Azufres there is a condensing unit of 50 MW, whose characteristics resemble the aforementioned units in Cerro Prieto. Additionally, there are two small binary cycle units, each one 1.5 MW, wich make use of the heat produced by geothermal brine to yield a second fluid, such as iso-pentanol (Figure 6).

In the geothermal field at Los Humeros there, presently, exist seven units of backpressure and atmospheric discharge type, each with an output of 5 MW, very similar to those, previously mentioned, located in Los Azufres.

SCALING PROBLEMS

Depending on the conditions and chemical composition of the steam, solid particles deposits can present themselves in the turbine nozzles -- especially those in the first stage -- which decrease the area in which the steam can pass. This in turn reduces generation while increasing admission pressure in the turbine. Therefore the "cleaning" of the steam represents



an important factor in the periodic maintenance of the units, something that in time not only has repercussions in the overall output but the plant factors itselves.

It has been observed, through operational experience, that scaling of turbines has not been a grave problem in Cerro Prieto, which is reflected in the generation of energy and its lofty plant factor (in the order of 92%). Neither has this been a problem in Los Azufres, among the backpressure units, which allows for maintenance to be performed approximately once every two years.

In spite of this, however, serious problems have arisen in Los Humeros because of deposits of salts and solid suspended in the steam. Generally these are not removable by conventional separation equipment currently installed there.

Various studies and analysis have been carried out in order to determine the mechanisms responsible for this buildup in the generating units first stage of nozzles. Upon reviewing the results of this studies, two areas of deposit have been singled out. The first area is in the concave side, where salts and solids accumulate through inertia and fail to continue on due to erosion which causes wet steam to collide with the salt cap. The other side occurs in the convex area where the loosening of the limit layer perturbs the local pressure. Consequently, the evaporated drops are saturated in salts which are deposited in this area of the nozzles.

The scaling of salts greatly influence the generation of energy in so far as it obstructs the passage of steam. Therefore the distance between the nozzles is a very important factor in this process: a small separation accelerates the formation of deposits while a larger one slows it down making it less severe.

Wherefore, the adequate selection and design of equipment is of the utmost importance. This will afford the user a geothermal steam that is "cleaner" and, at the same time, limit the time the unit is out of service.

STEAM PURITY

Steam that is extracted from the subsoil brings along with it a large quantity of salts and solids, such as silica, boron, calcium carbonate, sodium, chlorine and iron compounds, that in combination with gases provoke corrosive and scaling environments.

Results from the chemical studies and analysis of the fluids, performed in the three geothermal fields, reveal the characteristics shown in Table 2.

Table 2.- ***Average characteristics of fluids in geothermal fields in Mexico.***

FIELD	AVERAGE RESERVOIR TEMP. (°C)	ENTHALPY (kJ/kg)	SiO_2 (ppm)	T.D.S. (ppm)
CERRO PRIETO	320	1500	650	25000
LOS AZUFRES	280	2200	600	2500
LOS HUMEROS	300	2400	620	1800

The presence of iron compounds in the steam pipeline causes the formation of an anticorrosive film but when humid steam, concentrated in salts, carries sodium chloride along with it, this in turn reacts in such a way that the iron becomes active permitting that which is loosened to travel suspened in the steam. If the separation equipment, therefore, isn't adequately efficient these impurities will reach the turbine.

In the superheated steam, which is produced by some wells, there are solids in suspension produced by corrosion and sand that travel together in the steam, from the reservoir to the surface. Normally it is very difficult to remove such solids with conventional separation equipment which results in its arriving to the turbine. The collision of these solids, together with sand, ends in a wearing away of the machine, especially in parts such as blades and nozzles.

On other hand, to the same degree in which the water drops that accompany the steam, ascend from the reservoir to the surface, they begin to evaporate so that in the majority of cases they become oversaturated with salts. When these drops are not removed by the separation equipment, they arrive to the turbine thereby scaling the first stage of nozzles. Principally these solids deposits in the convex side of this area due to the loosening of the limit layer thus submitting the flow to pressure variations which in turn produces localized evaporation of the water transporting the salts, therefore creating deposits and scaling.

STEAM AND TURBINE WASHING

One way to reduce the deposit of salts and the consequent scaling in the turbines, is to clean the steam as well as the turbine.

The "cleaning" of the steam consists of injecting water into the steam conduction pipes so as to dilute the salts which are being transported suspended in the steam. Later on, the water salt saturated water drops are largely removed through the use of separation equipment. In this process steam from the very same well is used, condensing and then reinjecting it into the system by means of Venturi washers and pumping systems.

This steam purification system has been implemented in the installed units in both Los Azufres and Los Humeros, considerably reducing the concentration of salts while, at the same time, increasing the quality of the steam itself.

One case in point is Unit 2 in Los Humeros. Since the start of its commercial operation in 1991, this unit continually diminished its generation falling ultimately to 1 MW in a few hours, due to intense depositing in the nozzles.

The unit did not posses adequate separation equipment nor permanent steam washing system resulting in a generation rating in the order of 2.6 MW. But after the implementation of a permanent washing system, in 1992, generation increased to 5 MW without augmenting its consumption of steam. Figure 7 shows the schematic steam and turbine washing system employed in this unit.

Efficiency of washing systems can be affected by the effectiveness of the contact of the injected clean water with salts suspended in the steam and, also, by the efficiency of the dryers. But it is also related to the design of principal equipment, thereby making it compulsory to consider certain factors beforehand which can cause a greater degree of scaling in the turbines. These factors are:

- Distance between separator and dryer.
- Efficiency of thermal insulation of steam pipe.
- Type and distance between turbine drains.
- Installation of cleaning pipe of system.

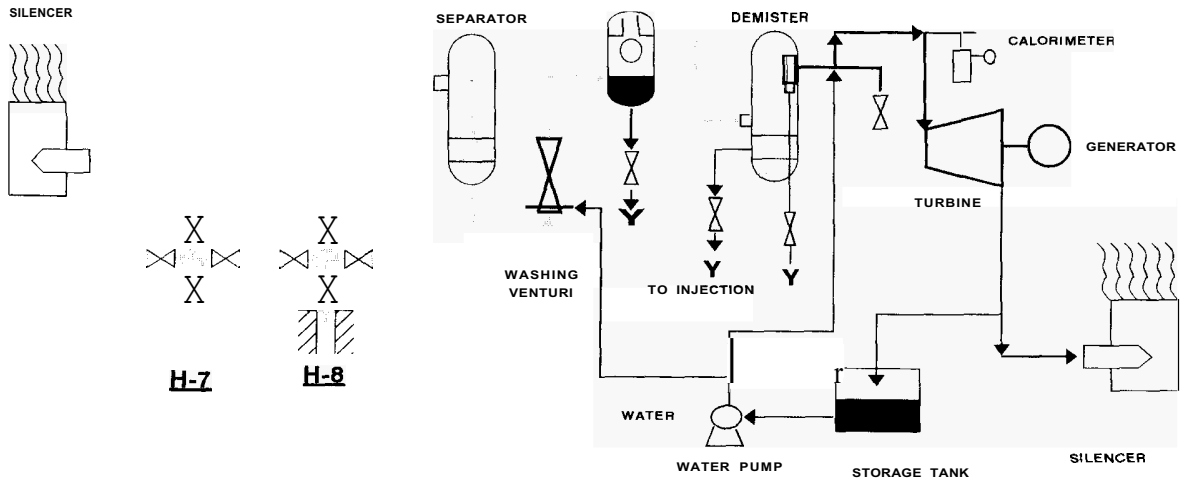
In particular, the efficiency of thermal insulation of the steam conduction pipes should not be too high, as to permit a greater dilution of salts.

After operational experience of steam washing systems in the geothermal plants in Mexico, general criteria have been adopted in order to reduce scaling of turbines. They are:

- Content of sodium in condensed steam inside turbine should be maintained below 0.03 ppm, while at the same time the condensed steam in the exhaust should be less than 0.4 ppm.

- Quality of steam admitted into turbine, by injection of water from the exhaust, should not be less than 1 % or more than 2 %.

FIG. 7.- STEAM AND TURBINE WATER WASHING SYSTEM IN UNIT 2, LOS HUMEROS



■ Electric conductivity in exhaust condensation should be held below 50 mmhos-cm.

Other systems exist which permit the removal of salt deposits in the first stage of nozzles. One of which is the washing of the turbine without having to take the unit out of operation of full load. In this manner the turbine's power is recovered when clean water is injected after the dryer, making use of the effect of erosion of the water. In this way small drops fall over the scaling areas removing salts and solids in an efficient manner.

The primary factors affecting the washing of the turbine are concentration of silica and solids dissolved in steam, and the design and construction of turbine.

SELECTION OF GENERATION EQUIPMENT

After more than 20 years of experience in the geothermal field of electrical generation, the following criteria have been applied in the selection of units and equipment for new projects in Mexico.

Unit Size

Modular units are best, preferably between 20 and 30 MW. The 30 MW units are the largest modular units manufactured to date. They offer the following simplifications:

■ Mounted on metalic base and in three sections: lubrication equipment (tank, pump, and control panel); turbine, and generator. This type of arrangement reduces construction time to 12 months, allowing the unit to be put into operation quicker. Moreover, they are tested in the factory and not in the site to be installed.

■ Electric generator in this type of unit is air cooled; hydrogen is not used, which simplifies the equipment while reducing the cost.

■ Placement of steam pipes is also simplified -- 4 to 6 wells are required to supply one unit -- reducing construction time of surface installations and, subsequently, total project cost.

■ Simplification of steam pipes layout minimizes the environmental impact produced by these jobs.

■ Total cost per kW installed is more competitive.

Admission Pressure

An admission pressure of approximately 7 bar is considered more convenient due to the following reasons:

■ Operation of relatively low admission pressure decreases moisture discharged from the turbine, which allows for a longer life of the blades, more time between routine maintenance and augmentation of the unit plant factor.

■ Possibility of integrating wells with modest wellhead pressure, which makes more efficient the use of extracted energy from the reservoir.

■ Utilization of this pressure enables the placing of wells close to the curve point where maximum energy can be obtained.

Rotation Velocity

Proper rotation velocity in a turbine is considered to be 3600 rpm due to the following:

■ Even though greater velocity implies a smaller turbine, 3600 rpm is preferable. The other way would require larger velocity reductors, which in turn would be a source of greater noise at the same time diminishing the efficiency of the unit.

■ Design of a 3600 rpm unit permits a larger area by which the steam can pass consequently rendering the unit less susceptible to depositing of salts and solids. Also, units that rotate faster develop scaling much more easily.

Gas Extraction Equipment

In the installed geothermal electric units in Mexico, two types of gas extraction equipment are used: turbo-compressors and ejectors. Operational experience of said equipment leaves the following evidence:

■ Operation of turbo-compressors is complex. The control system, similar to that of a large unit, frequently presents problems of vibration and operation. It is not possible to change the velocity of the compressor since recirculation is necessary to maintain a constant flow of gases within the condenser. For this reason equipment of this type is incapable of compensation for variations in the production of gases in the field.

■ Ejectors are reliable having no mobile parts. Nevertheless, operational cost is high due to the quantity of steam it consumes.

Actually, at present, there are plans to implement hybrid systems for the extraction of gases, meaning ejectors in the first stage and vacuum pumps in the second. It is expected that this will significantly reduce specific consumption of steam within units.

CONCLUSIONS

■ Of the three Mexican geothermal fields, the one in Los Humeros has presented more problems with depositing and scaling of turbines. This has obliged them to make intense studies and analysis for the purpose of identifying the mechanisms that cause scaling in the first stage of nozzles in the turbine and to reduce the time the unit is put out of service.

■ Two areas of salt depositing in the first stage of nozzles have been identified. The first is in the concave side where, because of inertia effect, the salts and solids deposit, and the second is located in the convex side where deposits occur due the lossening at the boundary layer which is subjected to a varying flow of pressure, producing local evaporation of water accompanying the steam.

■ In the geothermal fields in Mexico washing of the steam and turbine has been implemented to avoid, in good measure, the scaling in the first stage of nozzles. Good results have been obtained using these systems, extending the period between each routine maintenance and limiting the diminution of units generation.

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