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H_2S DISPERSION MODEL AT CERRO PRIETO GEOTHERMOELECTRIC POWER PLANT

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ABSTRACT

The concentration levels of H_2S in the atmosphere produced by the geothermal production activities at Cerro Prieto Geothermal power plant, located 30 km south to the city of Mexicali, Baja California, Mexico, are studied.

By using the compilation and analysis of actual measured values of H_2S concentration and utilizing a gaussian model of atmospheric dispersion, the expected levels of atmospheric H_2S are estimated in seasonal terms, annually and its spatial distribution. These estimations are made to consider the effect of the installation of a new plant at different capacities on the populated areas close to the geothermal field, and in the work areas in the vicinity of the plants. According to an official announcement, this year will start the construction of a new plant of 100 MW capacity at Cerro Prieto in the area of the Ejido Hidalgo.

It is concluded that the present and the expected levels of atmospheric H_2S are not a risk for public health, in the populated towns near the geothermal field, assuming a risk treshold of 30 micrograms/kg (parts per billion). However there are work sites within the geothermal installations where expected levels are close to 300 parts per billion.

1. INTRODUCTION

The objective of this work is to estimate the point and seasonal distribution of the gaseous emissions of the hydrogen sulfide (H_2S) from the chimneys/vents of the generation plants in the Cerro Prieto geothermal field.

The particular objectives are:

- to establish the actual distribution of the gaseous emissions of H_2S coming from the chimneys/vents of the generation plants at Cerro Prieto based on analysis of observed data;
- to apply the gaussian concept of pollutants dispersion to the data collected;
- to establish the effectiveness of the gaussian model corresponding to the data observed;
- to apply the gaussian model to the seasonal estimation of the spatial distribution of the emissions in the area that includes the points of generation and inhabited places in the vicinity of the geothermal site and
- estimate the effect of the construction of another generation plant upon the medium levels of H_2S concentration.

2. BACKGROUND

Some of the environmental effects (Resendiz, 1993) from the generation of electric energy based on geothermal resources are:

- Disturbance of the ecosystems during drilling of wells;
- Risk of pollution of soil and water by brine, during well drilling;
- Emissions of CO_2 and H_2S, during the operation of the power plants; and
- Subsidence of terrain, due to extraction of geothermal fluid.

Independent of the risk of the geothermal exploitation, geothermal power presents advantages with respect to other sources of energy, as it is a renewable resource and its technology in Mexico is very well known. Therefore geothermal power is economically attractive at the places where it is available. Increasing oil prices in the international market also make geothermal power attractive.

3. METHODS, TECHNIQUES, MATERIALS AND STUDY AREA

3.1 Emission Points.

At the Cerro Prieto field the points of emission of H_2S and other non-condensable gases are the vaporduct purge mufflers, condenser chimneys and at the cooling towers. The non-condensable gases are separated from condensed steam vapor in the condensers and expelled with the help of ejectors at the chimneys to atmosphere. There are five chimneys at Cerro Prieto plant I, and one per unit at Cerro Prieto II and III, making a total of seven. At nearly all the emission points, with the exceptions of the chimneys, the non-condensable gases are diluted by large volumes of steam vapor. The concentration of H_2S as a percentage in volume in the cooling towers is 0.04 %, while at the chimneys is 1.99% for Cerro Prieto I and 2.35% for the other plants.

3.2. Monitoring of H_2S Concentration

Although an official Mexican standard that regulates the level of concentration of H_2S does not exist, concentrations that exceed 300 μg/kg are considered human health risk. Despite of the absence of a standard, CFE (the Mexican electricity utility) should inform the environmental authorities of the concentration of hydrogen sulfide present in the field. For that reason, systematic monitoring has been practiced starting in 1993. The monitoring points are located within and outside of the field. These consist of: the lunch room at the Cerro Prieto I; the laboratory of Cerro Prieto I; and well M-94.

3.3. The Thermoelectric Process at Cerro Prieto.

The Cerro Prieto Geothermoelectric field is located approximately 30 km to the southeast of the city of Mexicali.

It extendeds for about 40 km^2 and includes thermal manifestations such as water lagoons, hot mud, fumaroles, mud volcanoes of about 5 cm to 2 m heigth and a volcanic cone called Cerro Prieto due to its dark color that may be seen from a distance, and which gives its name to the field. It is considered a liquid -dominated field, as the geothermal fluid is found in two phases. Most recent studies estimate the productive area extends over 25 km^2 (Mercado, 1988) . The drilling of exploratory wells started with M3 and M5 wells. The results of the exploration led to the construction of Cerro Prieto I plant, with a 180 MW capacity. Additional exploration to the east of M5 well gave rise to the installation of Cerro Prieto II and III plants, each with a 220 MW capacity. These plants started operation between 1984 and 1985.

3.3.1 Cerro Prieto I Plant.

The Cerro Prieto plant uses an open Rankine cycle.

In a normal Rankine cycle, the working fluid, normally water, is heated and vaporized under high pressure, to produce a saturated or an over-saturated vapor. This vapor is introduced in a turbine, where it is expanded producing work and comes out in the form of saturated vapor of high quality in the case of a reversible turbine. In the real case it is obtained saturated vapor or slightly overheated. The fluid that comes out of the turbine is condensed and pumped back to the boiler, usually with preheating.

In the case of the geothermal plants, vapor of high quality is available, typically greater than 99.5% dryness, which is sent to the turbines. Part of the exhaust vapor of the turbines comes out to the atmosphere mixed with the non-condensable gases, composed mainly of H_2S, CO_2 and NH_3. The remaining vapor is carried to the direct contact condenser to recover the water and replace water lost in the cooling towers by evaporation.

3.3.2 Cerro Prieto II and III Plants.

The wells that provide geothermal resource to Cerro Prieto II and III plants are 2000 to 3000 m dep. At the maximum depth of these wells, the geothermal fluid registers temperatures of about 367º C. The fluid from these wells undergoes a double flash separation, before the vapor enters the turbines.

The exit vapor at each turbine is sent to a direct contact condenser, which is fed with water from the cooling towers. Several turbocompressors are used at the condensers to extract the non-condensable gases. The turbocompresors are fed with high pressure vapor and discharge vapor to the low pressure line.

3.4. Environmental Effects of the Generation of Electric Energy at Cerro Prieto

The environmental effects of the generation of electric energy at the Cerro Prieto geothermal field have not been studied thoroughly, although some data has been published on the effect on the environment from a physical point of view (Rojas,1994), and on the emissions to the soil and air (Instituto de Ingenieria, 1994).

The geothermoelectric plants may cause adverse effects to the environment in two stages:
1) During the exploration and development of the field, and
2) during the extraction and distribution of the fluid and in operation of the systems.

The environmental effects due to the operation of the geothermal power plants are associated mainly with conduction and disposition of the geothermal fluid and its components.

The geothermal fluid is a mixture of hot water and variable impurities such as gases and salts. The presence of gases is explained by the contact of the fluid at high temperature with the minerals of the rock. In the geothermal reservoir, processes of solution and chemical equilibrium occur, which gives rise to the formation of certain gases.

During the process of extraction, in its path along the length of the well bore, the fluid undergoes changes of pressure and temperature that affect the chemical equilibrium. These chanages gice rise to additional dissolution and precipitation. The sources of pollution at this stage may be located at the following points:

- at the wells, by means of the risk of fractures in the surface equipment;
- at the separators, based on the risk of ruptures by overpressure;
- at the condensate purge points of the vapoerducts (steam piping);
- at the silencers;
- at the condensers by means of the disposal of the condensed vapor;
- at the ejectors through the final disposal of the non-condensable gases;
- at the cooling towers, through the continuous emission of vapor and non-condensable gases if direct contact condensers are used; and finally,
- at the reinjection systems base on the possibility of spillage and collapsing of wells.

The environmental impacts that at this stage may take place include: air, water, soil, thermal and noise pollution.

3.4.1 Air pollution.

The main problem of the non-condensable gases carried in the vapor is not its effect on the generation or conduction equipment, as there are ejectors or air expellers at different parts of the process; but the fact that the gases are released to the atmosphere The most important points of emission in the geothermal process are: chimneys for venting the non-condensables, evaporation of non-condensables at cooling towers, silencers, drainage and traps in the vapordu cts (steam pipes) and elimination of excess condensate from the cooling towers.

The emissions of non-condensable gases could be eliminated, if the gases from the ejectors were captured, compressed and reinjected back to the reservoir. Unfortunately, the work required for this operation would be a significant part of the plant's performance, therefore this alternative is not economically feasible, especially if it was not planned from the beginning (Di Pippo, 1990).

The principal composition of the non-condensable gases is CO_2 and H_2S,plus smaller quantities of NH_3, CH_4 and H_2.

3.4.2 Air emissions

The non-condensable gases are separated from the direct contact condensers using ejectors at a rate of 1.9 Kg/s (Garcia, 1989) then sent to the turbocompresors and discharge to the atmosphere through the chimneys. In adittion, gas emissions take place at the silencers due to the evaporation of the fluid at high temperature and low pressure, and by evaporation at the cooling towers that handle condensed vapor.

4. USE OF THE GAUSSIAN MODEL.

The utilization of the gaussian model at Cerro Prieto was carried out taking into account the following stages:

- Exploration of the model to explain real data. At this stage, it was intended to justify the use of the model in conditions not examined by the real data measured. The basic idea is that if the model results are useful to explain the real data, it is expected that it will be successful as well in the simulation of different conditions, within the limitations of the former. For that, it is necessary to automate the use of the Gaussian model using a computer program, whose results will be validated with published information. Once validated, it will be possible to rely on the computer program in the following cases:
  - Apply the model to all the individual data in which it is possible to have the necessary meteorological information as well as the concentration of H_2S;
  - To contrast the results of the model with the measured results. It will be possible to search the data for a statistical correlation between the estimated and the real data. An attempt will be made to explain the differences that may be found;
  - Use of the model in the simulation of cases not backed by real data. At this stage it was indented to use a model to simulate the pattern of concentration in an area not covered by the measured data, which included 5 Km distance towards each cardinal point taking as a center each one of the plants. With this, it is intended to establish an actual profile of concentrations in the vicinity of the field, for different seasons, trying to identify zones and times in which this profile results in health risk for the inhabitants living nearby the plant; and
  - Estimation of the simulated air quality effect from the construction of a fourth plant of similar characteristics to those already established.

This exercise has as an objective of trying to locate the position of a future plant that under the simulated conditions contribute to the most acceptable H_2S concentration tendencies.

4.1. Atmospheric Dispersion

Some limitations of the gaussian model that are important to know are:

a) the estimated concentration by the model is an average concentration;
b) the wind velocity in the direction of the plume does not change;
c) chemical reactions between the emissions and the atmosphere, or between the emission components do not occur;
d) the effective height and variance parameters are estimated empirically.

In spite of this limitations, this model is used frequently, and it has been noticed that the longer the average periods considered, the estimation is closer to the observed data, with an approximation of 20-30% for annual periods (Zanetti, 1990).

Therefore, as the gaussian model estimates the average concentration, it is not expected that the estimated conditions will match the real ones. What is attempted is a congruency of the tendencies by the model versus the observed ones.

Only the contributions by non-condensable gases from the chimneys will be considered, although the cooling towers, in absolute terms, discharge comparable quantities of non condensable gases, in terms of H2S concentration this contribution may be negligible, as these quantities are discharge diluted by larger amounts of water and vapor, which in the end comes out in significantly smaller concentrations as compared to those emitted at the chimneys.

The application of the model to the individual data was made based on a computer program and taking into account the following equation:

$$\overline{C}(x,y,z)=\frac{q}{2\pi\bar{u}\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma^2_y}\right)\times\left[\exp\left(\frac{(z-h)^2}{2\sigma_z^2}\right)-\exp\left(\frac{(z+h)^2}{2\sigma_z^2}\right)\right]$$

Where q is the emission (mass/time) and h is the effective height of the plume from he emission point, x y z are the coordinates in the space relatives to wind speed. The determination of σ_y and σ_z is given in terms of an atmospheric stability.

5. RESULTS

A program with the gaussian model for plane topography and without obstacles was developed. The program was verified with results obtained in the literature and later was utilized for the following cases:

a) Estimation with real data:

H_2S concentration data was utilized from the measurements collected at three points within and three points outside the geothermal field in the period considered between 1993 to 1994. This measured real data were contrasted with the data obtained from the computer simulation program. The fractional biases were estimated, and mean comparison tests were conducted. The fractional biases that were obtained were as an average 0.63 without using the correction for averaged time and of 0.9 using such a correction. When the mean comparison test was applied to the all of the points, it was allowed to accept the hypothesis that the mean of the concentrations obtained with the model is equal to the mean of the measured concentrations.

b) Estimation of the present situation.

A statistical analysis of the measured concentrations at the different points shows the following percentages of the hourly measurements that registered less than 30 ppb:

- Ejido Hidalgo: 97%
- Cerro Prieto I laboratory : 54%
- Lunch room at Cerro Prieto I: 82%
- Ejido Patzcuaro: 89%
- Well M-34: 100%
- Ejido Oaxaca: 98%

The computer program was run to estimate the annual and seasonal average concentration at different points of the field, taking into consideration a gridline of 12 x 11 km with nodes at each 500 m. This calculation is supplemented by the measured data at only three points in the field. The results for the annual period are shown in Fig. 1. Considering this period, the annual concentrations in the Ejidos Hidalgo are in the order of 9 ppb, while in the area of the generation plants it is up to 30 ppb.

c) Effect of the installation of a new plant and its capacity.

The program was run considering a new plant as a source of pollutants for annual and seasonal periods. The new source is considered as emissions coming first of all, from a plant similar to Cerro Prieto II and III, to be constructed at Ejido Hidalgo and in a different exercise another plant of 20 MW capacity. The simulation was also realized for different capacities of plants at two different locations within the geothermal field.

The results of this simulation for the annual period are presented in Fig 2. The grid considered in the program was widened to observe the effect at places located further away. It may be observed that also in this case the reduction of the concentration at Ejido Hidalgo takes place in NE-SW direction. The estimated annual effect would be the increase of concentration at Ejido Hidalgo and Ejido Oaxaca to 9 to 12 ppb. In the furthest inhabited areas from the geothermal field like Ejidos Nuevo Leon, Jalapa, Hipolito Renteria and Michoacan de Ocampo would be detecting H_2S concentration between 3 and 6 ppb.

To estimate the effect of the capacity of the plant, a simulation was carried out locating a new plant at two different potential sites, at jido Hidalgo and at Ejido Patzcuaro. The annual H_2S concentrations may be seen in Figs. 3 and 4, even with plant capacities of 220 MW like those ones at Cerro Prieto II and III, the annual H_2S concentration does not get to 30 ppb at these places. Locating the plant at Ejido Hidalgo would increase the H_2S concentration at Ejidos Nuevo Leon and Oaxaca up to levels close to 12 ppb, and at Ejido Michoacan de Ocampo with constant concentration at any capacity of the generation plant. If the plant is located at Ejido Patzcuaro then Ejido Oaxaca gets the same effect, but at Ejidos Nuevo Leon and Michoacan de Ocampo the effect is not significant.

The effect of a new plant on the worksite would increase levels close to 175 ppb if the plant is located at Ejido Hidalgo, whereas the effect is smaller if the plant is located at Ejido Patzcuaro, as it is shown in Fig. 5.

6-CONCLUSIONS AND RECOMMENDATIONS.

- The gaussian dispersion model for pollutants is adequate to describe the tendency of the spatial distribution of the concentration media of H_2S at Cerro Prieto considering an annual period.
- The use of the gaussian model in this case gives better results if the correction for averaged time is not used.
- Currenty the annual average concentrations of H_2S at the work site is about 130 ppb. This level is not risky for human health, although the smell is detectable. The peak concentrations exceed this level and in some cases rise to acceptable health risk levels.
- The actual H_2S annual average concentrations in the populated areas next to the geothermal field are about 13-14 ppb. These levels do not exceed acceptable human health risk levels.
- The dilution rate of H_2S is dominant on the NE-SW axis.
- The construction of a plant of 20 MW at Ejido Hidalgo would produce an annual level of average concentrations of H_2S between 3 and 6 ppb at settlements located relatively far away from the Ejidos Michoacan de Ocampo, Hipolito Renteria, Nuevo Leon y Jalapa. For the areas closer to the plant, like the Ejidos Hidalgo,and Oaxaca. The installation of such a plant would have the levels of concentration of H_2S between 9 and 12 ppb, being critical during the fall and winter seasons.
- The more favorable location of the new plants is an area close to the Ejido Patzcuaro.
- The installation on new plants of the capacity of Cerro Prieto II and III would increase the annual average concentration of H_2S up to a level of 5 ppb in the areas further away from the Ejido Michoacan de Ocampo, and at a level close to 15 ppb at Ejido Oaxaca. For the working area, the concentration of H_2S would reach around 160 ppb.
- The availability of a meteorological year database is recommended for the use of the gaussian model.
- The adoptions of safety measures are recommended to protect human health at the work site as much as in the populated areas close to the plant. These measures will to prevent of events that may increase the instantaneous concentrations of H_2S, to human health risk levels.

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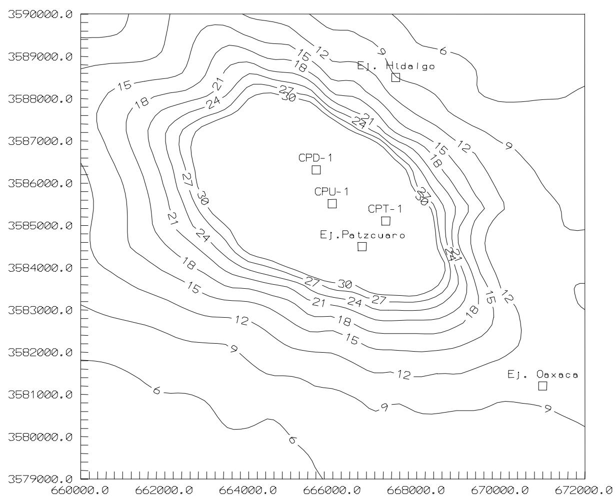

Figure 1 Concentration levels of H_2S for the yearly period. Present estimation-

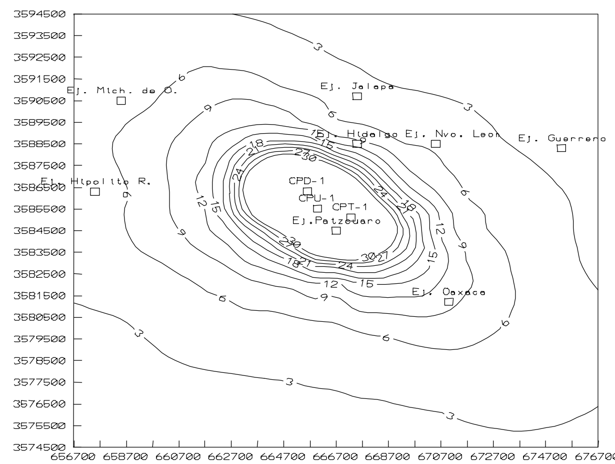

Figure 2. Concentration levels of H_2S for the yearly period. A 20 MW plant located at Ejido Hidalgo is considered.

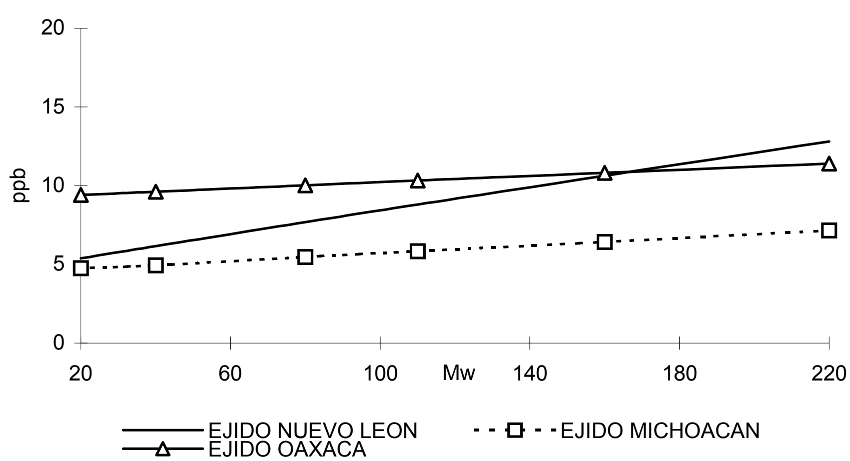

Figure 3. Effect of a new power plant located at Ejido Hidalgo on populated areas.

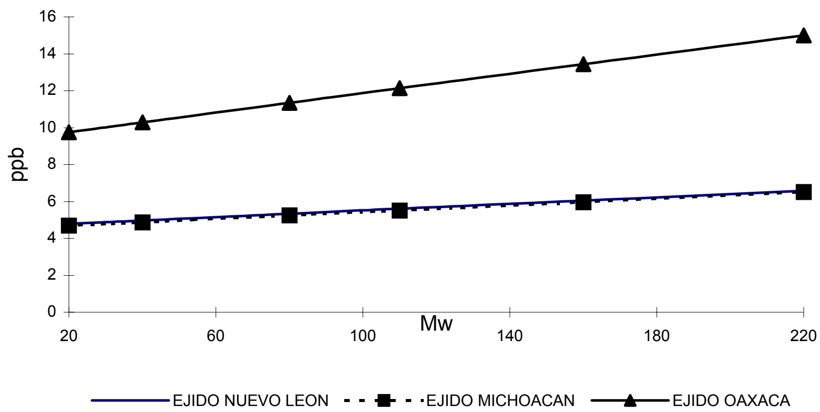

Figure 4 Effect of a new power plant located at Ejido Pátzcuaro on populated areas.Dara corresponding to Ejido Michoacán and Ejido Nuevo León lay on the same line.

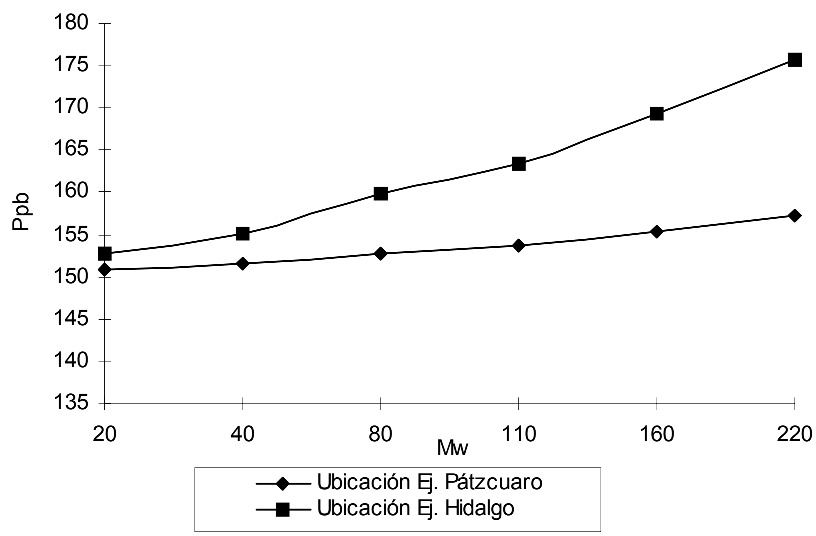

Figure 5. Effect of a new power plant on labor areas.