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IMPACTS OF GEOTHERMAL WELL TESTING ON EXPOSED VEGETATION IN THE NORTHERN NEGROS GEOTHERMAL PROJECT, PHILIPPINES

Josefo B. Tuyor, Agnes C. de Jesus, Reinero S. Medrano,
Jo Rowena D. Garcia, Sherwin M. Salinio and Leonora S. Santos

PNOC Energy Development Corporation, Merritt Road, Fort Bonifacio, Metro Manila 1201, Philippines

ABSTRACT

The impacts of geothermal discharges during the testing of Pataan 5-D well in the Northern Negros Geothermal Project were evaluated on seedlings of mahogany (Swietenia macrophylla King) at various distances from the well and on natural forest vegetation around the pad. Parameters measured were: 1) geothermal brine spray concentration, 2) plant concentration of geothermal signature ions (B, Cl, Li, Na), 3) symptoms of plant damage and 4) plant recovery. Meteorological parameters were also gathered. Adverse effects on the test plants were observed at 5-50 meters from the silencer during the horizontal discharge and at 50-350 meters from the wellhead during the vertical discharge. Salinity was identified as vector of plant damage. Observed symptoms of damage included drying of leaf tissues expressed as necrotic areas, which occurred first at the tip of older leaves and progressed along the margins as severity increased resulting to abnormal defoliation. Recovery of seedlings and natural vegetation from sprays of horizontal and vertical discharges were 70% and 100%, respectively.

1.0 INTRODUCTION

Well testing during geothermal exploration is conducted to characterize the physical and chemical properties of the geothermal fluid, the permeability and fluid state of the reservoir and the power potential of drilled wells. During well testing, geothermal fluids are released into the atmosphere at relatively high temperatures and pressures. The fluids contain salts (basically sodium & chloride) and other elements such as arsenic, boron and lithium, which may have detrimental effects on sensitive plant species that may be reached by the geothermal spray.

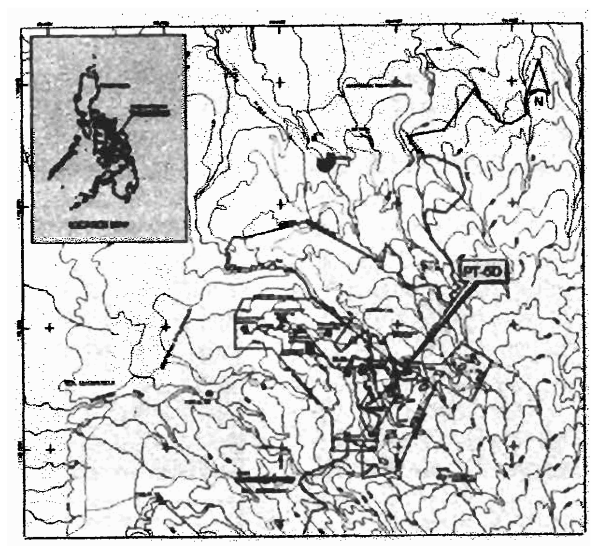

Figure 1. Location of the study site.

This study was conducted with the following objectives: 1) to document, characterize and evaluate the impacts of both vertical and horizontal well testing on exposed vegetation, 2) to identify the vectors of damage, 3) to determine the threshold of exposed . plant species as regard to the levels of relevant geothermal elements, and 4) to determine the allowable duration of discharge without mitigation that will not cause death to exposed plants.

2.0 METHODOLOGY

2.1 Study Site

The study was conducted in the Northern Negros Geothermal Project at the vicinity of well PT-SD located in the Pad B area in Sitio Pataan, Brgy. Mailum, Bago City, Negros Occidental (Figure 1).

2.5.2.5 Chemical Analysis of Geothermal Fluids

The profiles of the potential vectors of damage, such as the daily levels of geothermal ions at the weirbox and temperature, were recorded.

The geothermal brine sprays collected in the catch basins of each station were collected at the same time seedlings were harvested. The brine was washed off from the basin with 300-ml de-ionized water. The washings were analyzed for geothermal indicator ions.

3.0 RESULTS

The horizontal discharge of well PT-5D was conducted for 45 days while the vertical discharge was conducted for a total of 10 hours or approximately 2.5 hours/discharge. The impacts of vertical discharge in the present study represented the worst scenario considering that the standard vertical discharge for Philippine wells only lasts for 30 minutes at any single time.

3.1 Meteorological Parameters

The meteorological readings at the study site during the discharge are shown in Table 1. The ambient temperatures at the 5-m radius of the silencer and at the forest edge (250 meters away from the silencer), were recorded between **23°C - 25°C.** Temperature readings at 5-m and 50-m radius were not different.

Table 1. Meteorological readings at the study site'

Month	Ambient Temp. (°C)		Wind Direction'	Wind Speed (m/s)	Rainfall (cm)
	5-m radius	≥50-m			
May	24.45	24.52	NE	1.27	2.94
June	23.96	24.50	NE	1.24	3.14

The most dominant wind directions during the discharge were northeasterly (NE) followed by southeasterly (SE). The NE winds predominated in the entire course of discharge. Other wind directions recorded were southwest (SW), south (S), east (E) and northwest (NW). Winds speeds and rainfall levels in May and June were comparable. Higher rainfall levels were recorded during the discharge.

3.2 Chemical Analysis

Table **2** shows the levels of B, Cl, Li, Na and pH at the weirbox. The pH of the well was generally neutral (ave. pH = 6.96) since acidizing of the well was done prior to discharge. This **also** isolates pH as a vector in the analysis.

Table 2. B. Cl. Li. Na and pH levels in the weirbox'

pH	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
6.96	259.00	15.542.00	33.92	8.215

'Average of the entire 45-day discharge

The concentrations of B, Cl, Li and Na in the geothermal sprays collected from the catch basins, as shown in Table 3, decreased with distance from the silencer. The highest concentrations were recorded within the 5-m radius. The same trend was also recorded from the washings (Table 4) and the leaves of the test seedlings (Table 5), and from the exposed soils (Table 6). In contrast, ion levels in the control remained low.

Exposed natural vegetation also manifested elevated ion levels during the discharge compared to the low pre-discharge levels (Table 7). Likewise, the ion levels in the control were lower than those from the exposed.

Table 3. B, Cl, Li and Na levels in the geothermal sprays collected from the catch basins during horizontal discharge'

Distance from the silencer	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
5-m	79.05	5,228.55	6.46	2,902.52
15-m	37.58	3,230.67	2.93	2,028.43
30-m	21.60	1,418.33	1.85	742.59
50-rn	13.04	838.94	1.13	425.29
75-m	7.32	492.07	0.70	263.48
100-rn	4.89	304.79	0.41	162.18

'Average of 9 collections

Table 4. B, Cl, Li and Na levels detected from the washings of the test seedlings[1]

Distance from the silencer	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
Control	<0.10	2.95	<0.01	0.45
5-m	0.25	26.67	0.05	11.71
15-m	<0.10	8.23	0.02	3.53
30-rn	<0.10	5.06	0.01	1.38
50-m	<0.10	3.06	<0.01	1.23
75-rn	<0.10	2.92	<0.01	0.93
100-rn	<0.10	2.57	<0.01	0.53

Table 5. B, Cl, Li and Na levels in the leaves of test seedlings exposed during horizontal discharae'

Distance from the silencer	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
Control	28.50	3,800.00	6.15	591.83
5-m	784.09	48,317.58	34.04	23,263.78
15-m	536.28	33,426.21	25.35	15,354.95
30-m	528.94	24,515.00	19.14	11,278.11
50-m	188.81	21,438.81	18.47	9,986.34
75-m	161.35	15,696.03	18.29	5,316.19
100-m	130.22	13,190.95	12.33	4,018.10

'Average of 9 collections

Table 6. B, Cl, Li and Na levels in soils exposed during horizontal discharge'

Distance from the silencer	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
Control	2.11	304.29	<0.10	111.71
5-m	35.39	1,914.44	2.33	957.99
15-m	17.01	1,456.58	0.56	501.42
30-m	9.67	794.32	0.47	311.82
50-m	7.75	553.58	0.18	219.13
75-m	6.74	529.71	0.21	198.83
100-m	7.55	450.09	0.16	185.67

* Average of 9 collections

Table 7. B, Cl, Li and Na levels in the leaves of natural vegetation during vertical discharae'

Distance from the wellhead	Boron (ppm)	Chloride (ppm)	Lithium (ppm)	Sodium (ppm)
Control	24.00	2,730.00	22.00	1,050.00
Pre-discharge	28.00	2,970.00	18.00	1,420.00
20-m	250.00	21,112.00	19.00	6,903.00
50-m	267.00	27,266.00	25.67	10,490.00
75-m	283.00	23,200.00	15.00	9,200.00
100-m	203.00	21,600.00	17.00	9,170.00
125-m	280.00	22,050.00	16.00	4,190.00
150-m	235.00	14,400.00	12.00	3,800.00
200-m	200.00	10,000.00	10.00	2,210.00

'Average of 2 verticalbischarges at 6 replicates/discharge

3.3 Biological Parameters

3.3.1 Effects of Horizontal Discharge on Test Seedlings and Natural Vegetation

Early damage symptoms assessed a day after the discharge included drying of leaf tissues or dessication observed as necrotic areas, which occurred first at the tip of older leaves and progressed along the edges or margins as severity increased, resulting in abnormal early defoliation on the second day after discharge (Figures 3a - 3d). The impact zone is confined within the 50-m radius of the silencer regardless of the wind direction. Test seedlings at 5-30 meters from the silencer, manifested symptoms a day after the discharge, while those at 50 meters manifested five days later. Natural vegetation were not affected during the horizontal discharge. No impact was observed for seedlings exposed at 75-100-m range. In terms of extent of plant damage and recovery, seedlings within the 5-15-m range were severely affected compared to seedlings at 30-50-m distance.

3.3.2 Effects of Vertical Discharge on Test Seedlings and Natural Vegetation

Due to the angle of dispersion, the impact zone of vertical discharge started only at 50 meters up to 350 meters from the wellhead, and only at the plume direction (NNW) and its immediate left (NW) and right (NE) quadrants. The impact zone is beyond the 50-m radius of the pad. Thus, only the natural vegetation (50m - 350m) within this zone were affected. Damage symptoms manifested were similar to those observed from the test seedlings during the horizontal discharge, except that defoliation started only on the 6th day after the first vertical discharge.

3.3.3 Recovery Observations

Test seedlings exposed to the horizontal discharge have varying degrees of recovery (Table 8). Severely affected seedlings at 5-15-m distance and those with longer exposure registered low recovery rates. The reverse was noted for those exposed at 30- and 50-m range and those with short exposure. The overall recovery rate of seedlings exposed to horizontal discharge is about 70%. In contrast, the natural vegetation exposed to vertical discharge registered a 100% recovery three (3) months after the discharge (Figures 4a – 4d).

Table 8. Percent recovery of test seedlings exposed to horizontal discharge'

5-m	15-m	30-m	50-m	75-m	100-m
45%	58%	82%	92.5%	not affected	not affected

'distance/station.

Figure 3a. Test seedlings before horizontal discharge.

Figure 3b. One day after the start of horizontal discharoe.

Figure 3c. Seven days after the start of horizontal discharge.

Figure 3d. Thirty days after the start of horizontal discharge.

Figure 4a. Natural vegetation during vertical discharge.

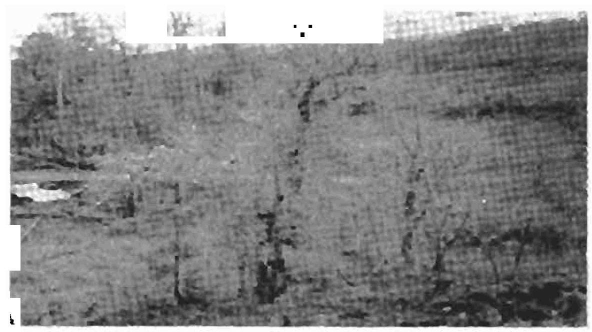

Figure 4b. Nine days after the first vertical discharge.

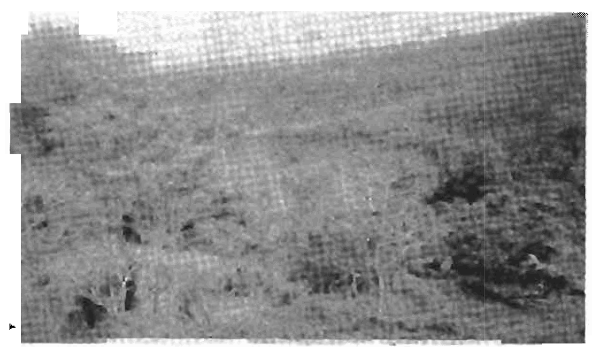

Figure 4c. Three (3) months after the completion of vertical discharge.

Figure 4d. Three (3) months after the completion of vertical discharge.

4.0 DISCUSSION

There is a dearth of information on the effects of geothermal sprays on vegetation. The results of the study can serve as reference in developing measures to prevent or minimize the adverse impacts on vegetation. This is important in forested geothermal areas with forest cover in the light of the growing concern for biodiversity and life-support systems in the environment.

4.1 Vectors of Damage

In the present study, three potential vectors of damage were assessed, namely: I) temperature, 2) salinity and 3) toxic ions. Temperature as a vector has been ruled out, as ambient temperatures measured within and outside of the impact zones were not significantly different. Defoliation also occurred at 50 meters and beyond from the wellhead, where ambient temperatures are comparable with those recorded from the impact zone.

The possible vector of damage, based on symptomatic manifestations, is salinity. Early symptoms of affected plants, including drying of leaf tissues, which occurred first at the tip of older leaves and progressed along the edges or margins as severity increased, are signature symptoms of salinity (Futch and Tucker, 2001; Peacock, 1998; Seawell and Agbenowosi, 1998; and, Ayers and Westcot, 1976). Excessive leaf drying is often accompanied by abnormal early defoliation (Ayers and Westcot, 1976).

According to Alsup (1998), salinity affects plants in three major ways, as follows: 1) water deficit, 2) ion toxicity and 3) nutrient imbalance. This study seems to support the first effect. The drying up of leaves indicates water deficit due to the withdrawal of water following the water concentration gradient (high water concentration in the plant cell to the low water concentration in the saline geothermal spray). On the other hand, there were no signs of black patches that are typical of toxic ion dumping on cells. One of the toxic elements, Li, from geothermal sprays seems to be not a factor in plant damage since the levels detected are below those that may cause plant injury (Schauss, undated). Parameters measured were insufficient to assess mineral nutrition effects. Table 9 shows the tolerance limits of plants to salinity, which had been exceeded in the study. Salinity as a vector, rather than toxicity, is consistent with the observation of the damage manifested in older leaves as against ion toxicity, whose prime targets are the younger leaf tips with more water fractions. In the study, deaths in younger shoot tips appearing as black spots, which are due to toxic ions, were not existent.

Table 9. Tolerance limits of plants to salinity[1]

Salinity Ions	Upper Limits (ppm)	Optimum Range (ppm)
Boron	0.80	0.20 - 0.50
Chloride	140.00	0.00 - 50.00
Sodium	50.00	0.00 - 30.00

[1]After Cyberconference: water quality for woody plants, part I by Hannah Mathers of Oregon State University.

4.2 Possible Mode of Uptake

While the levels of ions in soils are high, obviously the direct contact of leaves with ions from geothermal sprays seems to be the main cause of damage, basing from the immediate dessication response of the test plants as early as the first day after the discharge. The saline ions of Na, Cl and B may have been absorbed directly by the test plants through the cuticular openings of the leaves. This was confirmed by the presence of salt deposits on the leaf surfaces of test plants especially at 5-15-m distance range. Uptake from the root systems may have taken place for test plants with prolonged exposure, and this maybe one of the reasons why recovery rate was very low for those plants with prolonged exposure.

4.3 Threshold of the Exposed Vegetation

The combined LC_{50} of the three saline ions measured from the geothermal spray, which caused >50% mortality on the test seedlings, is at 8,000 ppm (B=79ppm; Cl=5200ppm; Na=2900ppm). This was recorded within the 5-m radius from the silencer. Other ion contributors need to be studied, including the kinetics of ion transport to determine what causes the decrease in ion levels with distance from the well.

4.4 Recovery of Affected Vegetation

The recovery of affected plants was dependent on the Concentration of geothermal ions absorbed from the sprays and the duration of exposure. Test plants close to the silencer, which were exposed to higher ion levels, expectedly have low recovery than those exposed farther (<50%). The same is true for test plants, with prolonged exposure to discharge, presumably due to their continuous exposure and possible ion uptake through the roots. Recovery was also dependent on age of the affected plants, with seedlings recovering poorly compared to the natural vegetation. Nelson (1991) cited that seedlings are more sensitive to salts than established plants. This may be due to the capacity of mature plants to buffer stresses or repair altered processes.

The drying up of plant tissues and cells is also expected to cause the alteration in ultra-structure or the cell organelles, which are the seat of important life processes. Irreversible alteration leads to death of the plant parts (Cortez, 1978).

The present study confirms the earlier observations noted in the other geothermal projects of Philippine National Oil Company – Energy Development Corporation, the geothermal developer of the Philippine government, in Mt. Labo, Mt. Apo and Leyte. Observations indicate the temporary impacts of geothermal discharges. Defoliated vegetation has fully recovered in a range of one week to years after the well testing in various sites (Fernandez, 1993).

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the study indicated that one of the possible vectors of vegetation damage during the geothermal well testing is salinity, brought by the high concentrations of saline ions in the geothermal brine sprays released from the discharging well. The study also showed that the impact zone of horizontal discharge is confined within a limited area compared to that of the vertical discharge. In this study, the horizontal discharge only affected the pad area. Thus, vertical discharge is more critical to vegetation than horizontal discharge since the pad area is normally cleared of vegetation. It was also determined that the severity of vegetation damage is dependent on 3 factors, such as: 1) resulting brine spray concentrations, 2) distance of vegetation from the well, and 3) prevailing wind direction during the discharge. The study also confirmed the temporary impact of well testing on vegetation.

REFERENCES

Alsup, C. M. (1998). Salinity: causes and effects, and management practices. Sourced from the internet at http://www.geocities.com/clydealsup/Salinity.htm

Ayers, R. S. and Westcot, D. W. (1976). Water quality for agriculture. Irrigation and drainage paper 29, Food and Agriculture Organization, Rome, Italy.

Cortez, A. R. (1978). The growth responses of *Phaseolus* vulgaris L. cv. "White Baguio" to low water status. Unpublished M. Sc. Thesis, Univ. of the Philippines, Diliman, Quezon City, Philippines.

Fernandez, C. S. (1993). Hydrogen sulfide and sulfur dioxide from geothermal sources: its effect on forest vegetation. Unpublished M.Sc. Thesis, Univ. of Canterbury, Christchurch, New Zealand, 139 pp.

Futch, S. H. and Tucker, D. P. H. (2001). A guide to citrus nutritional deficiency and toxicity identification. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611, USA.

Mathers, H. (undated). Cyberconference: water quality for woody plants. Oregon State University, USA.

Nelson, P. V. (1991). Greenhouse operation and management. 4th ed. Prentice Hall, Englewood Cliffs, USA.

Peacock, 8. (1998). The use of soil and water analysis. University of California Cooperative Extension, Tulane County, California, USA.

Schauss, A. G. (undated). Lithium. Sourced from the internet at http://www.sonarm.com/research/lithium.htm.

Seawell, C. and Agbenowosi, N. (1998). Effects of road deicing salts on groundwater systems. Groundwater Pollution Primer, CE 4594 Soil and Groundwater Pollution, Civil Engineering Department, Virginia Polytechnic Institute and State University, Virginia, USA.