Air Quality and Plant Eco-Physiological Responses Around Geothermal Power Plants in Iceland and Kenya

Thecla Mutia1,2, Ingibjörg Svala Jónsdóttir2, and Þráinn Friðriksson3

1United Nations University, Geothermal Training Programme, Reykjavik, Iceland
2Department of Life and Environmental Sciences, University of Iceland, Reykjavik, Iceland
3ISOR, Iceland Geosurvey, Grensasvegur Reykjavik, Iceland
tmum@unugtp.is • tmmutia@gdc.co.ke

Keywords
Environmental, Racomitrium lanuginosum, Tarchonanthus camphoratus, plant injury, emissions, power plants

ABSTRACT

As with most energy development technologies, environmental effects must be anticipated. Geothermal energy has proven intrinsic reliability and environmental viability compared to other finite and infinite energy sources. Nonetheless; further studies to complement existing monitoring and mitigation measures is the cumulative impact of H2S and trace element emissions to vegetation. Believed to be a source of S, H2S may contribute significantly to plant nutrition or if in excess act as a phyto-toxin. Given the anticipated and progressive world geothermal development, an understanding of the emission cycle and potential effects to vegetation is pertinent toward planning and executing feasible mitigation measures toward sustainable development. Presented herein are research plans within the Nesjavellir and Hellisheiði geothermal power plants in Iceland and Olkaria geothermal power plant in Kenya. Two key questions guide the study; 1) plant species response to changing air quality and manifestations? 2) concentrations of potentially phyto-toxic geothermal elements in plant species around power plants and threshold levels? The moss Racomitrium lanuginosum (Iceland) and the shrub Tarchonanthus camphoratus (Kenya) will be evaluated for signatures of any potential damage and growth stimulatory effects at varying distances and transects from the power plants. Concentrations of H2S - S, As, Hg, B and Sb will be traced in steam, air and related to the concentrations in plants and soil. All measured concentrations and effects will be correlated to controls for comparison and inferences. In an outdoor experiment, the two plant species shall be re-grown in trays and irrigated with different known levels of H2S dissolved in distilled water to determine threshold levels and responses. Findings of this study are expected to significantly aid in determination of the cumulative impacts of geothermal emissions to native plant species, and input to considerations of the evaluation of H2S and emission control strategies/ abatement systems. Further advising policy makers and reducing any anticipated development ambiguities or opposition. This will ultimately strengthen the impetus promoting geothermal energy as the ‘green’ solution to world energy needs.

1. Background

Environmental effects associated with geothermal energy development are considerably low compared to other energy sources. Through a comprehensive environmental impact assessment and a holistic environment management plan, anticipated effects can be mitigated. This paper focuses on geothermal power plant emissions and plant eco-physiological responses as power plants are relatively long-term compared to effects which may arise during well testing.

Amongst the accelerated world development of geothermal resources in the effort to replace fossil fuels with clean energy sources (Bertani, 2012), phyto-toxic emissions associated with geothermal development may remain a challenge. Even though abatement technologies exist, they remain un-implemented in most countries due to associated costs.

The main potentially phytotoxic substances released by the power plants are boron and hydrogen sulphide (Busotti et al., 1996). The former exerts its toxic action primarily on the soil (cf. Bergmann, 1992). Bonneau (1988) reports boron optimum concentration in the leaves of various tree species ranging between 30 to 70 ppm, while Bergmann (1992) only reports damage in conifer needles at concentrations higher than 100 ppm. In plants, low levels of H2S are beneficial to growth at atmospheric concentrations ranging from 0.03 to 0.1 ppm (WHO, 1981; Thompson and Kats, 1978). Concentrations in the range of 0.3 to 3 ppm cause injury to most plants and higher concentrations result in leaf lesions, defoliation and reduced or stunted growth, with young plants being most affected (WHO, 1981; Dani and Loppi, 1994; Thompson and Kats, 1978). In soil; H2S is known to cause root asphyxia affecting plant growth (Maas et al., 1987, 1988; Lisjak et al., 2013). There is however limited information on the possible impact of As, Hg and Sb phytotoxicity from atmospheric emissions and their tolerance levels in plant tissues (Busotti et al., 1996; Lisjak et al., 2013). In relation to geothermal emissions,
an understanding of the emission cycle and potential effects to vegetation and soils is pertinent toward planning reliable and relevant mitigation measures.

Other environmental effects include geothermal waste waters, however managed through cased re-injection wells restraining potential ground water contamination. During well testing geothermal over sprays according to Tuyor et al. (2005) are limited to a well pad devoid of vegetation with usually very minimal ecosystem effects. However in cases of vegetation occurring in close proximity of 350 m and less from the well head, symptoms may include mild leaf necrosis and abnormal defoliation. The impact is however temporary with plants exhibiting recovery.

1.1 Case Examples, Iceland and Kenya

Studies on the effect of geothermal power plants in Iceland and elsewhere have confirmed plant injury with occurrence of lesions, reduced plant growth and defoliation within a few hundred meters from the power plants (Helgardottir et al., 2013; Lisjak et al., 2013; Verkráfoístofan Efla, 2009; Bargagli et al., 1997; Bussoti et al., 1996). In Iceland, the most common plant species occurring around the Nesjavellir, Hellisheidi and Svartsengi geothermal power plants is the moss *Racomitrium lanuginosum* which obtains its nutrients from precipitation, dust and to a more limited extent, substrate (Glime, 2007) and hence would suffer serious physiological problems from air pollution (Bargagli et al., 2002).

In Kenya, the shrub *Tarchonanthus camphoratus*, is the dominating exposed plant around the Olkaria geothermal power plant and the Menengai geothermal field (earmarked for geothermal power generation by 2015 (Republic of Kenya, 2011)). There however exists limited literature on the impact of the power plant on *T. camphoratus* eco-physiology; further research is needed to understand if there are any macroscopic physiological effects that could be attributed to emissions from the power plant. It is also important to understand that accumulation of trace metals and sulphur in the foliage does not instantly result in tree health deterioration; but may be manifested as accumulated toxic materials on the forest floor due to foliage shedding consequently affecting soil biota and decomposition rates (Ferretti, 1996). An ecosystem can therefore be affected through subtle processes even when the effects are not macroscopic.

2. The Problem

The main potentially phytotoxic substances of concern released by the power plants are H2S, B, Hg, As, Sb and Rn whose toxic action manifests primarily on leaves and shoots of plants. The latter can have subtle ecosystem effects. To totally dub geothermal ‘green’ energy and enhance sustainability towards this progressive development, a study on the effects and tolerance levels of these elements on plants is vital toward air quality management; a complement to sustainable development.

Considering that most geothermal resources occur in the vicinity of ecologically significant and fragile ecosystems, with long-term power plant establishments, there is an urgent prioritized need to consider if there exists any linkage between volatile geothermal power plant emissions and their possible accumulation on selected bio-indicators such as plants, soil and potential effects. This will serve as a platform in planning and advising future mitigation measures toward sustainable development of geothermal resources.

3. Overall Aim and Objectives

The overall aim of the project is to understand the effects of trace elements and H2S gas emitted from geothermal power plants in Iceland and Kenya on vegetation occurring within the power plant environs.

Research Questions

1. Does the degree of plant injury, growth and morphology change with increasing distance from the power plant?
2. What are the concentrations of H2S, As, Hg, B and Sb in emitted steam and air from geothermal power plants?
3. What are the concentrations of S, As, Hg, B and Sb in plants and soils at varying distances from the geothermal power plants;
4. Is the concentration of S, As, Hg, B and Sb in plant and soils, a function of the concentration of those elements in steam emissions and distance from the emitting source (power plants)?, and
5. At what concentration is H2S gas (in precipitation) beneficial/injurious to plants and what are the effects on plant morphology and growth?

The specific objectives are

1. To assess the degree of plant injury, growth and morphology at varying distances from the power plants;
2. To determine H2S, As, Hg, B and Sb concentrations in steam emissions;
3. To quantify S, As, Hg, B and Sb concentrations in plant species and soils at varying distances from the power plants;
4. To establish the relationship between H2S, As, Hg, B and Sb concentrations in steam and accumulation in plant species and soils at varying distances from the power plant, and
5. To evaluate the effect of H2S gas (in precipitation) on plant species and determine tolerance levels through an experimental study.

Hypotheses

1. Degree of plant injury, growth and plant morphology is negatively affected by geothermal power plants;
2. The concentration of S, As, Hg, B and Sb in plants and soils decrease with increasing distance from the power plant;
3. The concentration of S, As, Hg, B and Sb in plant and soils a function of the concentration of those elements in steam emissions and distance from the emitting source (power plants);
4. The concentration of S, As, Hg, B and Sb in plant is lower than in soils and the difference decreases with distances to the power plant, and
5. Plant morphology and growth is affected by H₂S gas (in precipitation).

4. Conceptual Model and Justification

Figure 1 shows the conceptualized model of variables under study and their inter-relationship. The findings will act as a yardstick in planning and advising mitigation measures on regulation of all unwanted ecosystem effects as regards to air quality and in monitoring induced changes overtime due to technological advancements.

5. Methodology

5.1 Study Area and Plant Species Under Assessment

The Hellisheiði geothermal power plant since its commissioning in 2006 is the largest in Iceland having a current installed capacity of 303 MWe and 133 MWh. The Nesjavellir geothermal power plant on the other hand is the second largest in Iceland and began operation in 1990; to-date producing 120 MWe and 300 MW/1800 litres per second of hot water.

Olkaria II commissioned in 2003 is Africa’s largest geothermal power plant having an power output of 105 MWe.
5.2 Plant Response Assessment (Plant Injury, Growth), Plant and Soil Sampling

Study Design

In each study area, one transect will be selected in the direction of prevailing wind with sampling stations at 250 m, 1000 m, 4000 m (5 replicates per station). Two control study areas will also be established 100 km further away in areas devoid of geothermal activity as baseline comparison.

In each sampling station (measuring 4 m x 20 m), the following shall be assessed:

1. Degree of plant injury – These shall be categorized to different levels of visible injury with frequency measurements for R. lanuginosum and T. camphoratus;

2. Plant growth measurements – Height measurements shall be determined. Nylon mesh bags shall be set up for R. lanuginosum (Armitage et al., 2012; Glime, 2007), and vertical measurements for T. camphoratus (Kiruki and Njung’e, 2007);

3. Plant physiology – Level of sclerophyllia (Leaf Area Index/Dry Weight) and chlorophyll content shall be tested as indicators of plant stress in correlation to levels of sulfur in leaves using methods described in Bussotti et al. (2003).

5.3 Chemical Analysis

At each station, plant leaves and moss shoots (upper 2 cm being photosynthesis active) shall be randomly obtained. Soil samples shall also be obtained (5 cm cores). All samples shall be dried and prepared further for SO4-S, As, Hg, B and Sb analysis by use of mass spectrometry (ICP-MS). Concentrations of H2S, As, Hg, B and Sb in steam emissions shall also be determined by use of ICP-MS.

5.4 Experimental Study

There are scanty studies on the threshold limits for H2S and eventually sulfur in various vegetation types and the consequences thereafter. Studies by Kristmannsdottir et al. (2000) on the fate of H2S in air suggest a considerable proportion of H2S washed out of steam, precipitating as elemental sulfur in air and a small fraction oxidized to SO2. This is eventually dispersed and deposited in ecosystems with sulfur signatures manifested in part; vegetation and soil. Thompson and Kats (1978) and Li et al. (2012) report H2S concentrations being of benefit to vegetation at 0.1 ppm with increased germination and growth, however if exceeded the effects include leaf lesions, defoliation and reduced growth at 3 ppm in Medicago, lettuce, grapes, sugar beets, pine and fir.

While effects of H2S in humans have received ample attention on the consequences at different exposure levels, there is also need to amplify research on vegetation. This study is designed to assess the effects of different levels of H2S deposition in vegetation as an outdoor experiment to integrate natural optimal growth conditions. Vegetation not previously affected by geothermal emissions will be re-grown for a period of six months. The design is full factorial randomized blocking.

Experimental Set-Up - Iceland

Extracted R. lanuginosum samples from three areas devoid of geothermal activity will be weighed (sub samples biomass at time 0) and re-grown in a total of 16 0.5 m x 0.5 m trays in...
optimal moss growth conditions for a period of six months. The growth medium shall be gravel obtained from the sampled areas. H₂S gas dissolved in water at 0 ppb, 30 ppb, 100 ppb and 300 ppb concentration will be used to randomly irrigate the R. lanuginosum samples in each tray and replicated four times. The nylon mesh bags method (Glime, 2007) shall be used for height growth measurements. Measurements shall be made using a 60 cm length of 5 mm aluminum rod pushed well into the moss carpet at each tray.

Weekly observations will be made on potential plant changes (a chart shall be used to classify different levels of changes/injury) to estimate plant tolerance levels. After the experimental period, growth changes shall be estimated. The moss samples will be dried, weighed and analysed for total sulfur concentration using an ICP - MS.

Experimental Set-Up - Kenya
A total of 16 0.5 m x 0.5 m trays shall be used in holding seedlings of T. camphoratus (in plastic tubes with holes at the bottom) in optimal growth conditions for a period of six months. The growth medium shall be soil. Each tray shall contain 16 seedlings for each treatment randomly replicated four times. All plastic tubes shall be of similar sizes to avoid variation in size and height of different growth stages. H₂S gas dissolved in water at 0 ppb, 30 ppb, 100 ppb and 300 ppb concentration will be used to randomly irrigate the T. camphoratus samples in each tray.

Weekly observations will be made on potential plant changes (a chart shall be used to classify different levels of changes/injury) to estimate plant tolerance levels. Plant condition measurements shall include size (total biomass) and growth and will include stem and root lengths, plant stem diameter, number of stems and leaves at time 0 and at the end of the experiment. Leaves shall be assayed for total sulfur using an ICP-MS.

6. Statistics
Descriptive statistics shall be provided for each parameter assessed. Analysis of variance (ANOVA) with post-hoc LSD (least significant difference) mean comparisons will be used for univariate analysis of all parameters. To show the relationships, Multivariate regression analysis shall be performed. All statistical routines will be calculated with the program R version 3.0.1 (Good sport), Seefeld and Linder (2007).

7. Conclusion
The entire project shall commence in May 2013 for a period of one year. The expected output is expected to contribute as standard guidelines for vegetation/plant monitoring and threshold levels to phyto-toxic geothermal emissions around geothermal power plants in Kenya and Iceland based on dominating vegetation. The findings will also input to considerations of the evaluation of H₂S and emission control strategies/abatement systems. Further advising policy makers and reduce any anticipated geothermal development ambiguities or opposition. This is of utmost importance in ensuring sustainable development in the quest for accelerating the development of ‘green’ geothermal energy.

Acknowledgement
The authors wish to thank the United Nations Geothermal Training Programme, Iceland for funding and facilitating this ongoing study. The Geothermal Development Company Ltd, Kenya and Orkuveita Reykjavikur for co-facilitation.

References


Maas, F.M., Van Loo, E. N. and Van Hasselt, P. R, 1988. Effect of Longe-
Terme H$_2$S Fumigation on Photosynthesis in Spinach, Correlation
between CO$_2$ Fixation and Chlorophyll a – Fluorescence. *Physiol. Plant.*
72, 77–83.

Republic of Kenya, 2011. Updated least cost power development plan, Study

University of New Hampshire, Durham, NH.

Thompson, R. C. and Kats, G, 1978. Effects of continuous hydrogen sul-
phide fumigation on crop and forest plants. *Environ. Sci. Technol.,* 12
(5), 550-553.

Tuyor, B. J., De Jesus, C. A., Medrano, S. R., Garcia, D. J., Salinio, M.
S., Santos, S. L, 2005. Impact of geothermal well testing on exposed
vegetation in the Northern Negros Geothermal project, Phillippines.
*Geothermics,* 34, 257–270.

Verkraðistofan Efla, 2009. Rannsóknir á mosa við jardvarmavirkjun Orku-
Geneva.

1 Unique and spectacular habitats and wildlife areas that require protection and
conservation such as found near the Olkaria geothermal power plant (Kenya)
and the Nesjavellir and Hellisheidi geothermal power plants (Iceland).