Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Monitoring Protocol for Potential Hydrogen Sulfide Effects on the Moss (*Racomitrium lanuginosum*) around Geothermal Power Plants in Iceland

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Keywords: H_2S emissions, Sampling, *Racomitrium lanuginosum*, Monitoring, Sustainability

ABSTRACT

Following environmental concerns on the effect of H_2S gas emissions from geothermal power plant emission on ecosystems and especially moss heaths in Iceland, plant health assessment is paramount in ascertaining ecological sustainability. The effect of wet H_2S deposition on the moss *Racomitrium lanuginosum* from geothermal power plants needs to be established around all geothermal development projects with a continuous eco-toxicological monitoring plan. Determination of environmental variables such as wind direction, speed and topography is necessary in choosing sampling/monitoring points. Moss plant parameters such as growth, physiognomy, nutrient and tissue chemistry should be determined on a quarterly basis. Ambient H_2S concentrations should also be measured and correlated to moss tissue chemistry for potential relationships and effects. This paper presents different moss eco-physiological variables that should be measured and monitored on a quarterly basis to complement existing environment management plans around geothermal power plants in Iceland toward sustainable development.

1. INTRODUCTION

The unique Icelandic ecosystem is richly dominated by various associations of moss species with the *Racomitrium lanuginosum* forming a larger part of the moss heaths around most geothermal power plants and fields. Unlike higher plants, Mosses are directly dependent on atmospheric deposition for nourishment as they lack cuticle and rooting systems making them quite vulnerable to any forms of atmospheric pollution (Bargagli et al., 2002). Since they do not also shed their leaves as vascular plants do, they are susceptible to accumulation of toxic chemicals or excess nutrients in the event of atmospheric pollution. This can significantly affect their growth and physiology (Armitage et al., 2012).

In Iceland, 65% of primary energy emanates from geothermal (Ketilsson, 2012). The vast moss dominated eco-system has since shown compatibility with geothermal since establishment of the first power plant in the late 1970s. In 2008 however, the Icelandic Institute of Natural History (IINH) filed a report on dead mosses around Hellisheiði and Svartsengi geothermal power plants in Iceland (http://www.ni.is/frettir/nr/817 http://www.ni.is/frettir/2008/09/18) with concerns that the likely cause was gaseous emissions from the power plants probing further research. A study by Efla (2009) was then commissioned and results indicated concentrations of trace metals with more emphasis on sulfur.

Prevalently, all conventional flash geothermal power plants are documented to emit 95 – 98% steam with the rest constituting non-condensable gases. At Hellisheiði geothermal power plant in Iceland, emitted gases in steam comprise CO_2 58.1%, H_2S 29.4%, H_2 12.3% and CH_4 0.2% (Gunnarsson et al., 2013). According to Bussotti et al. (2003), other conventional gases emitted by geothermal power plants include O_2, N_2 and trace compounds or elements including radon, helium, arsenic, mercury and boric acid. These gaseous emissions are likely to cause environmental concerns; though there are established strategies for management which are however expensive and not adopted in many instances; e.g. H2S abatement technologies.

Biologically, CO_2 and H_2S are significant factors in photosynthesis. CO_2 is the limiting factor for photosynthesis at optimal light, temperature and moisture conditions while H_2S offers a significant macro-nutrient; Sulfur, essential for growth at optima concentrations (Shinn et al., 1976). These gases form significant inputs in the cycle of nature at ideal concentration. Nonetheless, out of all the gaseous elements produced, H2S is the main potentially phyto-toxic gas at excess concentrations whereas the other gases might be toxic, their concentration is considered to be trace. In view of that, studies on the effect of sulfur in plants are quite limited; however documented symptoms include foliar necrosis due to high concentration exposure and long-term exposure effects such as reduced growth, yield and chlorosis (Thompson and Kats, 1978). To mitigate such impacts, countries have developed stringent regulations and implementing agencies. Iceland for example will adopt new H_2S regulations restricting atmospheric concentrations to annual average concentrations of not higher than 5,0 $\mu g/m^3$ air and 24 hour average of not higher than 50 $\mu g/m^3$ air (Gunnarsson et al., 2013) by July 2014. Geothermal developers such as Reykjavik energy in compliance to the policy have established a five year study on vegetation monitoring and associated toxicology in association with Icelandic Institute of Natural History (IINH) around their geothermal power plants to yield baseline data and long-term measurements on the effect of geothermal power plants on vegetation (Helgadottir et al., 2013; Mutia et al., unpublished).

2. *R. LANUGINOSUM* MONITORING AROUND GEOTHERMAL POWER PLANTS

2.1 Choosing monitoring sites and set -up

A desktop survey using long-term meteorological data is relevant to establish the climate, prevailing wind direction and speed of the area. This yields vital information on gas dispersion. An understanding of the area topography is also critical since H2S being denser than air tends to settle in hollow areas. With this information, monitoring sites should in a systematic and random design be established along topographical gradients in the prevailing wind direction at close intervals near the power plant and further away. Evenly distributed and similar plots can then be established at each station and pegged. These demarcated monitoring sites should then be barricaded off and marked to avoid any kind of interference. The set-up should have the power plant cooling towers as the central point with an equal number of sampling stations in the prevailing wind direction and in the non-prevailing wind direction for comparison. A control station should then be established about 100 km plus away from the power plant. This can be identified with the aid of existing H2S dispersion models to establish areas without geothermal activity. At the control station, the monitoring set-up design and sampling should be similar to the sample stations at the power plants for comparison.

2.2 Plant eco-physiology and physiognomy

Plant eco-physiological parameters relate to tissue chemistry and can significantly affect plant growth among other important bio-chemical processes ultimately affecting plant yield. Chemical sampling and analysis can be quite limiting and strictly depends on available funds and equipment. Studies indicate moss growth at about 1cm per year (Armitage et al., 2012). This means that the upper segments of moss shoots can yield time- based information related to potential toxicology. Many studies will analyse the upper 3cm segments of the moss shoots being the most photo-synthetically active (Efla, 2009). These results will show accumulated effects over the past three years. Others partition the sampling and analysis based on the upper 3cm and lower 2cm to understand nutrient or potential chemical input and distribution based on aeolian or soil deposits (Efla, 2009). Standard moss eco-physiological measurements will include, but not be limited to chlorophyll concentration measurements e.g. using Jägerbrand et al., (2005), tissue chemistry for analysis of sulfur (S) concentration, and other important macro-nutrients such as phosphorus, nitrogen and potassium. The elements balance in certain rations with sulfur for different plants which if not balanced will result in stressed plants and acute manifestations of foliar necrosis. To estimate the nutritive balance, the same elemental levels in the control sites can be used for comparison together with existing literature. All sample analysis should be carried out using standard analytical procedures.

Plant physiognomy is basically the plant appearance. Different plant appearances can be categorized in groups, e.g. from healthy to damaged based on decided classes. Frequencies of occurrence of each category at the measurement plots can then studies and data recorded (Helgadottir et al., 2013).

2.3 Abundance

Using a square 1m x 1m sampling frame, abundance over time can be determined using the point frame method (Helgadottir et al., 2013). This is important in showing the plant distributions and potential effect areas.

2.4 Growth measurements

Sulfur comprises an important macro – element significant in plant growth at optimal concentrations. Growth can be estimated as biomass or shoot increase. Jónsdóttir et al. (1999) shows a standard procedure on estimating biomass while the cranked wire method or netlone mesh bags can be used in determination of vertical shoot growth (Glime, 2007).

2.5 Air quality measurements

Air quality data should be acquired on a daily basis using stationary H_2S loggers at the power plant area and vantage measuring points established around sample stations. These can be measured using calibrated and well-working hand held H_2S detectors.

2.6 Timeframe

The monitoring time frame should run for a period of five years to establish any observed trends or changes. Samples can however be collected on quarterly basis for chemical analysis and data trends studied overtime. Otherwise the other measurements can be scheduled annually.

2.7 Data analysis

Data acquisition should be regular and adequate over-time. Analysis can be carried out using approved and standard statistical analytical tools such as R for biologists. To determine the effect of the geothermal power plant emissions on R. lanuginosum, linear mixed models e.g. can be generated.

2.8 Target

It is necessary for all geothermal developers to develop a plant monitoring system for eco-toxicological studies to strengthen mitigation measures and avoid putting up such measures when environmental disasters strike. Further geothermal power developers are encouraged to establish such programs with immediate implementation.

Other countries mainstreaming vegetation studies include Italy (Bargagli, et al., 2002) and Kenya (Mutia, et al., on-going). See poster for a case study on the effects of wet hydrogen sulfide deposition on R. lanuginosum in Iceland at the Conference.

3. CONCLUSION

Efforts by Reykjavik Energy to complement geothermal development and ecological sustainability are timely in this advent of sustainable development. Italy and Kenya are also at the fore-front of promoting vegetation monitoring around geothermal power plants. With the growing environmental concerns and especially on hydrogen sulfide emissions from geothermal power plants and associated effects, such data will be important in justification of potential claims on the ecosystem effects of hydrogen sulfide. In addition for cases with observed effects, mitigation measures shall be implemented. This plan serves for information and guideline for developers who have not yet incorporated such programs in the monitoring framework.

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