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Modeling H_2S Dispersion from Proposed Menengai Geothermal Powerplant

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ABSTRACT

The Hydrogen sulfide gas released from the geothermal operations has a potential impact on the health of the workers and the community living within the vicinity and also the geothermal equipment. Similarly, this gas is a toxic pollutant when released into the atmosphere. Additionally, this gas is corrosive to metal-based materials including brass and iron when dissolved in water. In this regard, there is need to manage the concentrations of hydrogen sulfide in the atmosphere at acceptable levels without detrimental effects to components of the biosphere. In this study, a dispersion modeling of H2S emission was used to assess the concentrations of hydrogen sulfide within the vicinity of the power plant. The technique is carried out using atmospheric dispersion modeling system (AERMOD) which is a steady-state Gaussian model to determine the hydrogen sulfide concentrations in the atmosphere within the vicinity of the power plant. To achieve this goal, hourly meteorological data were captured and input to the Aermet processor. Since weather conditions heavily influence H2S concentration, statistical analysis is used to determine a correlation between the weather parameters and H2S concentration. The analysis provided a mechanism used in predicting the concentrations of H2S under different weather conditions. As such, it provided a basis to determine the likelihood of conditions that may exceed the recommended concentrations and their potential effects on the environment. . The prepared background and predictive model when combined show that although operations at Menengai Geothermal Project emit H2S gas, the concentrations are below the WHO set guidelines of 150 μg m-3 and therefore have a less impact on air quality. The findings are beneficial as part of regulations for air quality standards to reduce global warming and environmental degradation, the introduction of H2S abatement techniques and reduction strategies.

Keywords : Geothermal, Environment, Hydrogen sulphide, Menengai geothermal field.

I. INTRODUCTION

The growing demand for energy has created the need for countries to develop sustainable sources of power to meet the socio-economic development agenda. Consequently, this has forced many countries to look for alternative renewable sources of power. Geothermal power provides solutions since it is clean and sustainable. As such, Kenya has increasingly invested in geothermal energy to ensure a stable supply of energy to facilitate its industrialization agenda enshrined in the vision 2030(Simiyu 2010).

Geothermal energy is termed as a renewable energy resource because the interior of the earth maintains a limitless supply of heat energy. Sources assert that the pressure in the Earth's interior will retain this status in billions of years to come thus keeping a reliable supply of heat for the present and future generations. Geothermal power plants are specifically designed to capture and convert this heat into electricity. Nevertheless; geothermal development poses a challenge to the environment including surface disturbances, thermal effects, physical, noise, gas emissions and effects due to fluid withdrawal.

The global impact of air pollution has been quantified to be quite extensive. Specifically, air pollution has direct and indirect effects on humans. For instance, the human body absorbs the chemicals released from the geothermal sources posing a danger to the respiratory system and the human body at large(Simiyu 2010). Additionally, the pollutants released from geothermal development can affect the structure and functions of the ecosystems posing a danger to flora and fauna. Sources confirm that the geothermal fluids contain a number of non-condensable gases (NGC) such as CO_2 and CH_4 which are released to the atmosphere courtesy of the diffusive gas discharges (Seaman 2000).

Release of NCG to the atmosphere at any phase of the geothermal operation changes the chemical composition of the air within the vicinity. Among the NCG emitted, H_2S has a significant effect on the environment. The other gases emitted are CO_2 and CH_4. Studies conducted in various geothermal fields around the world reveal the harmful effects of hydrogen sulfide gas emissions on the nearby towns. Consequently, regulations have been put in place that requires geothermal power plants to reduce the level of emissions (Gunnarsson, Aradóttir et al. 2013). This study mainly underscores the impact of the emission of gases from the geothermal steam.

1.1 Hydrogen sulfide

H_2S is a colorless gas with characteristic rotten egg smell that distinguishes it from other gases. It is harmless in small quantities (<0.0047 ppm) and soluble in alcohol and water among other liquids.
OSHA records that the permissible exposure limit for hydrogen sulfide is 10 ppm. Also, OSHA confirms that an individual should not experience a peak exposure of 50 ppm for a duration exceeding 10 minutes. At concentrations between 500-100 ppm, hydrogen sulfide causes respiratory paralysis which translates into unconsciousness and asphyxiation. On the same note, World Health Organization (Organization 2000) asserts that inhaling hydrogen sulfide gas at this concentration can cause death.

As noted earlier, it is difficult to recognize hydrogen sulfide gas at low concentrations. However, the unpleasant odor (rotten egg smell) can help in detecting this gas. At concentrations between 500 and 1000 ppm, this gas can cause conjunctival irritation; also known as ‘gas eye.'

1.2 Problem Statement

Hydrogen sulfide gas released during geothermal development is considered to bring about significant environmental changes if no management and monitoring plans are put in place. In this regard, H_2S is corrosive and toxic in high concentrations. Many scholars have studied hydrogen sulfide emissions and their associated effects in different geothermal fields around the world. In these studies, H_2S has been found to pose serious environmental effects.

Since the effect of H_2S distribution at Menengai is unknown, this study will address the transportation and dispersion of the gas. Additionally, it will aid in getting a deeper understanding of the behavior of the gas concentration in relation to the prevailing atmospheric conditions.

1.3 Objective

The primary objective
The primary objective of this study was to model H_2S dispersion around the proposed Menengai geothermal power plant.
The specific objectives of the study were

1. To map out areas of high H_2S concentrations resulting from the emissions from the power plants using a Gaussian dispersion model.
2. To assess the effects of weather parameters on H_2S concentration and dispersion.

1.4 Significance

Human interventions affect the environment in one way or another. These interventions have led to significant pollution that has brought changes in environmental patterns. As such, the member states of the United Nations have come together to push the agenda of sustainable development. Every development begins and ends with the environment. Geothermal development will have environmental implications on the physical, biological and the social environment. Both the extraction of heat from the interior of the earth and the geothermal fluid has potential effects on the environment. As established earlier, the geothermal fluid contains none condensable gases including hydrogen sulfide gas that has a significant impact on the receiving environment. In this regard, this study was able to give a precise prediction of how many times the conditions favorable for high H_2S events were anticipated per year; in relation to the weather. Therefore, this study explores proper abatement techniques to adopt in future.

II. LITERATURE REVIEW

2.1 H_2S emission from Geothermal Power Plants

Geothermal power plants emit geothermal fluids in relatively high amounts. These fluids contain non-condensable gases (NCG) which can significantly change the chemical composition of the air when vented into the atmosphere. Similarly, natural gas discharge from geysers, fumerals, hot pools and natural springs can contain non-condensable gases. Of concern is the level of amounts produced during power generation. These fluids contain high amounts of dissolved gases such as methane, carbon dioxide, nitrogen, and hydrogen. However, the geological status of the site and the environmental factors such as temperature notwithstanding the reservoir composition; (Kristmannsdóttir and Ármannsson 2003) state that recent geological studies on geothermal discharges indicate that the level of gas concentration in most power plants is controlled by temperature which dictates the equilibrium in the minerals present in the reservoir rock. Similar research done in San Jacinto-Tizate contends to this claim.

(Karingithi 2002) studied the process of emissions in Olkaria geothermal power plant by using chemical geothermometers to determine the equilibrium between hydrothermal mineral buffers found that dominates the geothermal system and the reactive gases that are emitted from the system. (Zhen-Wu) focused on the secondary analysis of mineral assemblages that influence the concentration of the NCG gases present in Reykjanes Geothermal system, SW Iceland. Both (Karingithi, Arnórsson et al. 2010) and (Zhen-Wu) contend that the mineral composition of pyrrhotite, magnetite, prehnite, wollastonite, pyrite, pyrrhotite, prehnite and epidote informs the availability of hydrogen sulfide gas in the geothermal system.

(White, Lawless et al. 2008) argue that the presence of five alteration assemblages is usually an indication of possible emissions of H_2S from a geothermal well.

2.2 H_2S Atmospheric dispersion

Research has shown that the weather conditions affect the concentrations of H_2S. Also, oxidation occurs under favorable conditions. (D’Alessandro, Brusca et al. 2009) argue that H_2S concentration recorded in the urban areas of Thessaloniki and Sousaki; both in Greece are higher during the summer and lower during winter. The main hydrogen sulfide source in these areas was traffic with the possibility of oxidation. The research further indicates the need for more case studies on H_2S measurements around geothermal power plants.

According to (Kristmannsdóttir, Sigurgeirsson et al. 2000) the oxidation of H_2S to SO_2 within the Nesjavellir area, is at least slow. (Thorsteinsson, Hackenbruch et al. 2013) underscores that H_2S concentration was lower during the day and higher at night and also established that the levels of hydrogen sulfide rose beyond 50 mg/m³ in Reykjavik and was associated with certain weather conditions. Specifically, he established that the concentrations of hydrogen sulfide gas were higher in low wind conditions coupled with high pressure and low temperature. (Kristmannsdóttir, Sigurgeirsson et al. 2000) hold the opinion that the concentrations of this gas decrease with the increase in precipitation. (Patil and Patil 1990) have also estimated the impact of the emissions in thermal power plants analyzing the emission factors and trace elements present in the power plants.

2.2.1 Gaussian plume dispersion model.

For the past few decades, Gaussian dispersion models have emerged as better alternative tools for air quality management especially in the era when it was difficult to secure high-performance computers for environmental management purposes. Gaussian dispersion model had been used in various air quality studies in both the urban and rural areas. However, extreme environmental pollution such as the Chernobyl disaster pointed out the weaknesses of Gaussian dispersal model thus calling for a more sophisticated approach. Nonetheless, Gaussian plume dispersal model has been commonly used in studies involving both multiple and single sources of air pollution. The calculation is oriented to analyze how atmospheric stability and distance affect the ground level concentration of the pollutant. The software used in this model has an inbuilt set of algorithms to aid in the conversion. The formula below represents a simplified diffusion Equation

$$\frac{dC}{dt} + U\frac{dC}{dx} = \frac{d}{dy}\left(K_y \frac{dC}{dy}\right) + \frac{d}{dz}\left(K_z \frac{dC}{dz}\right) + S$$

.

Where: x = along-wind coordinate measured in wind direction from the source y = cross-wind coordinate direction

z = vertical coordinate measured from the ground

C(x, y, z) = means the concentration of diffusing substance at a point (x, y, z) [kg/m3] Ky, Kz = eddy diffusivities in the direction of the y- and z-axes [m2/s]

U = wind velocity along the x-axis [m/s]

S = source/sink term [kg/m3-s]

Gaussian- plume models assume that a steady state of pollution emission and meteorological conditions remain over a short time. However, the conditions can vary within a short time. As such, the formula provides a better representation if the conditions remain constant. The information gained from these forecasts helps environmentalists in determining environmental impacts and developing proper environmental conservation policies

III. RESEARCH METHODOLOGY

3.1 Introduction

This section discusses the study area and how the study arrived at the results detailed later. First; it gives the emission data obtained from the power plant, the meteorological data collected from the weather station located at 173363E, 9976379N with an elevation of 2153 m, and the reported H_2S concentration measurements carried out by an automatic gas detector (Jerome® J605 gas detector) around the power plant. Lastly, the Gaussian plume approach that was used in the study.

3.2 Project area

The Menengai Geothermal prospect is found at the central region of the Kenyan rift valley. It borders Lake Nakuru to the north and Lake Bogoria to the south. The Menengai Geothermal Prospect covers approximately 600km² characterized by complex geological conditions. Importantly, this zone lies at the triple junction where Nyanza rift joins the Main Kenyan rift. Pyroclasts from the volcanic activities cover the area. The Two rift floor tectonic-volcano axes, i.e., Solai TVA and Molo TVA define the geothermal system of the Menengai Geothermal prospect area. The Solai TVA faults have disturbed the ring structure on the North Eastern end. Studies confirm that one fracture at the SSW of the caldera wall extends southwards. The Molo TVA/Ol'rongai fracture system intersects the caldera on the NNW part. Most the lava filling the Caldera are attributed to the eruptions that released through the fracture openings.

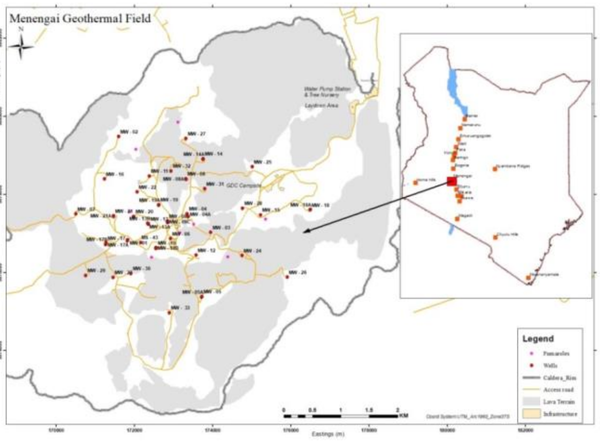

Figure 1: Location of Menengai geothermal field

3.3 Model Description

AERMOD means AERMIC Model, where AERMIC is the American Meteorological Society/EPA (Environmental Protection Agency) Regulatory Model Improvement Committee. This Model was developed in 1995. According to (Bluett, Gimson et al. 2004), the United States Environmental Protection Agency reviewed it in 1998 and endorsed it as the most suitable replacement for the Industrial Source Complex Short Term Model (ISC- ST3) in 2000.

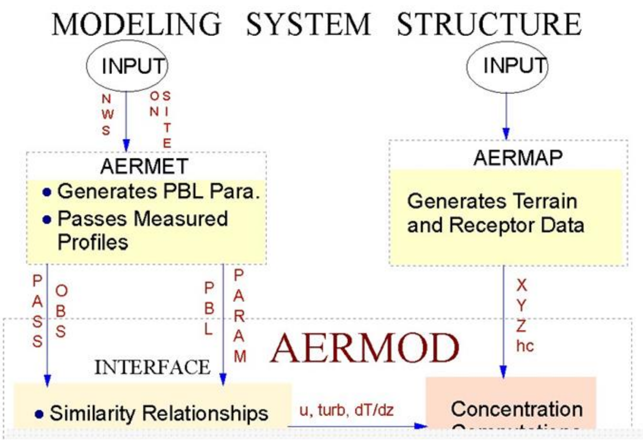

Figure 2: Data flow in the AERMOD modeling system.

3.4 Input data

3.4.1.1Meteorological data

Hourly surface observations of weather parameters were fed into the AERMET system, to convert the data into the suitable format for AERMOD. Based on the hourly surface data, the wind profile and Vertical temperature gradient were computed by the upper air estimator within AERMET. Surface characteristics are input to AERMET in the forming surface Bowen ratio, roughness, and albedo. The system then calculates the PBL parameters giving the temperature scale (2*), surface heat flux (H), Monin-Obukhov length (L), friction velocity (u*), convective velocity scale (w*) and mixing height (zi). Further, the parameters pass to the INTERFACE where the system utilizes similarity expressions to yield the lateral turbulent and vertical fluctuations (Fw, Fv) and Potential temperature (2) and potential temperature gradient (d2/dz)

3.5 Concentrations of H_2S in the project area

The Menengai geothermal project has an Air quality monitoring program that helps in measuring the concentration levels of H_2S in the ambient air. The baseline measurement sites represent the H_2S background concentration in the study field and the surrounding area. The results obtained from this program are reported on a monthly basis. A Jerome® J605 gas detector with a detection range of 0.003-50 ppm was used for measurements.

IV. Results and Discussion

4.1 Introduction

A simple Gaussian plume approach was employed to analyze the variation in concentration with distances from the source. Three various periods were modeled with regards to the weather patterns for every particular date and the H_2S concentration at the baseline level.

The results and the discussion have been presented together to facilitate and make the thesis more foreseeable. The first part of this chapter shows the results of the AERMOD model. This section also compares the concentrations of H_2S with the guidelines set by the WHO. As established in the literature review the feasibility of geothermal production heavily depends on some specified parameters which affect the sensitivity of the model.

4.2 AERMOD model results

Meteorological, power plant and terrain data for the period January-December 2013 were used to model three different periods in AERMOD.

Highest 24-hour average

The results from AERMOD shows the highest concentration averaged in 24 hours. Contours depend on the highest 24 hour average concentration by the receptor, established at various circumstances prevailing in different areas (Figure 3). The spatial conveyance of the plume for 24 hours averaging time stretches over a wide area found H_2S concentrations of up to 32.4 μg m^{-3}. The highest concentrations were recorded near plant building hitting a peak value of 32.4 μg m^{-3}.

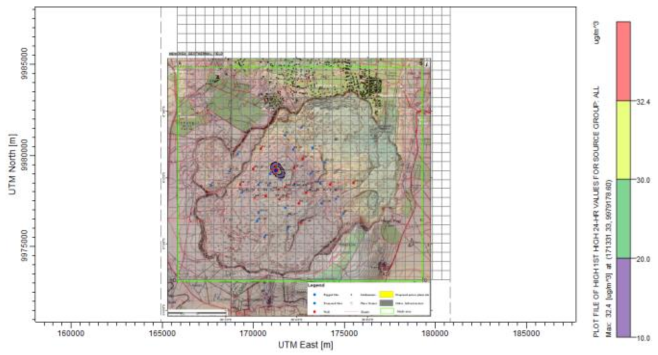

Figure 3: Highest H_2S 24- hour average concentration at any given location for the modeled the year 2013.

Highest 8-hour average

The study also modeled the highest concentration in 8-hour averaging. According to the study, none of the exposure limits averaged in 8 hour- time in the study are the exposure standards limits established by the World Health Organization (7100-14200 μg m^{-3}). The highest concentrations were recorded near plant building hitting a peak value of 74.5 μg m^{-3}.

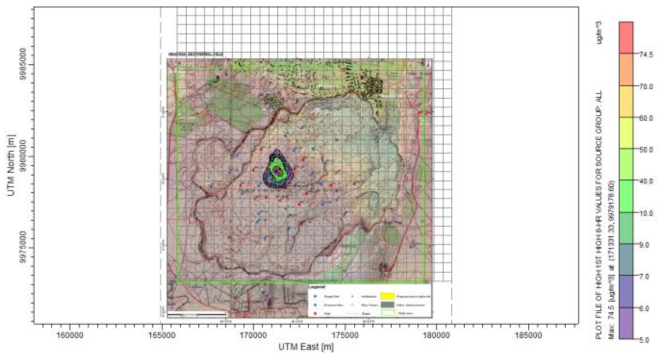

Figure 4: Highest H_2S 8- hour average concentration at any given location for the modeled the year 2013

Highest 1-hour average

One hour unit is the least averaging time that can be modeled in AERMOD. For a one-hour average, a single hour with the highest concentration amid the displayed year was taken by the receptor to assemble the concentration contours.

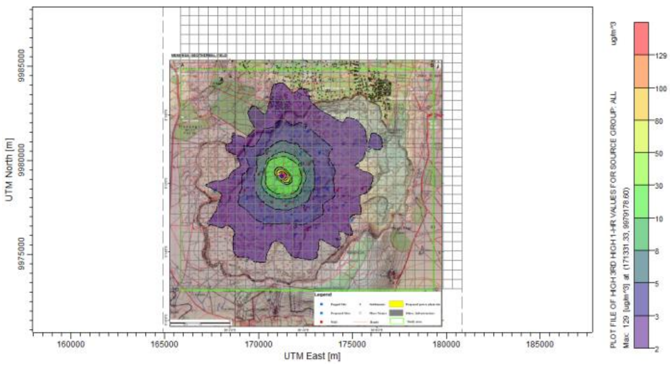

Figure 5: Highest H_2S 1- hour average concentration at any given location for the modeled the year 2013

The high concentration levels were recorded at the site between the powerhouse and the cooling tower; during the entire averaging times. This can be related with building downwash impacts since the development of air over and around the structures produces territories of stream dissemination, which can prompt high ground level focuses in the building wakes. The highest concentrations were recorded near plant building hitting a peak value of 129 µg m^{-3}. Hourly concentrations nearly meet the WHO ambient air guideline of 150ug/m3.The results above indicate that Menengai geothermal power plant does not significantly influence the chemical composition of the air within the vicinity. AERMOD model demonstrates that an H_2S outflow, for the most part, influences the air quality close to the project area. The encompassing towns are situated outside of the most well-known plume pathway; however, when displaying short averaging circumstances over an entire year, the focus is anticipated at some populated spots.

When comparing results from the AERMOD model with the measured averaged concentrations, the model anticipated low focuses for most of the points. Natural release of H_2S from fumaroles in the undertaking territory is not represented in the demonstrating; notwithstanding, these regular sources can influence the deliberate focus utilized for correlation with the model outcomes.

V. Conclusion and Recommendations

This chapter provides conclusions from the results and recommendations for further work

5.1 Conclusion

This study successfully used the AERMOD to establish the impact of H_2S concentration in the Menengai region. The corresponding concentrations of H_2S obtained from AQMS locations were used to validate the simulated model. It was established that the emissions from the power plant do not have any significant effects on the environment. Hydrogen sulfide dependency on different weather parameters was also analyzed. In this light, the easements associated high concentrations of H_2S to low precipitation, low speed of air and high air stability. In addition, the plumes that had wider spread were measured during unstable conditions. In this regard, we can make the following conclusions.

1. The concentrations of H_2S within the area do not exceed the hourly threshold established by the World Health Organization
2. Hourly concentrations recorded are higher when wind speeds are high.

5.2 Recommendations

The recommendations presented in this study are:

1. It is recommended that a more consistent monitoring programme for hydrogen sulphide emissions in Menengai be implemented since the field is expanding its production and this could increase hydrogen sulphide emissions and affect the air quality of Menengai. It is also recommended that deposition levels and identifying relationships between emissions, atmospheric loadings, and effects on human health and the environment be better characterised.

2. Research needs to be done to find out if Hydrogen sulphide can be reinjected with brine so as to eliminate environmental pollution totally from artificial sources.

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