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Modelling of hydrogen sulfide dispersion from the geothermal power plants of Tuscany (Italy)

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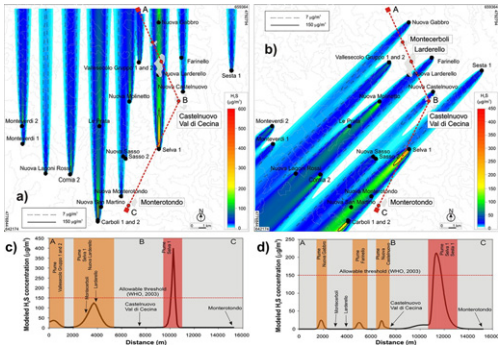
HIGHLIGHTS

- Hydrogen Sulfide dispersion modelling
- Hydrogen Sulfide concentrations and health risk for communities living close to the geothermal power plants
- Reliable prediction of Hydrogen Sulfide pollution in case of unexpected events
- Processes in the atmosphere involving Hydrogen Sulfide
- Comparison between results deriving from the model and observational data (field measurements)

GRAPHICAL ABSTRACT.



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ABSTRACT

We applied the Eulerian code DISGAS (DISpersion of GAS) to investigate the dispersion of the hydrogen sulfide (H_2S) from 32 geothermal power plants (out of 35 active) belonging to the geothermal districts of Larderello, Travale-Radicondoli and Monte Amiata, in Tuscany (Italy). An updated geographic database, for use in a GIS environment, was realized in order to process input data required by the code and to handle the outputs. The results suggest that H_2S plumes emitted from geothermal power plants are mainly concentrated around the stacks of emission (H_2S concentration up to 1100 μg/m^3) and rapidly dilute along the dominant local wind direction. Although estimated values of air H_2S concentrations are orders of magnitude higher than in unpolluted areas, they do not indicate an immediate health risk for nearby communities, under the more frequent local atmospheric conditions. Starting from the estimated values, validated by measurements in the field, we make some considerations about the environmental impact of the H_2S emission in all the geothermal areas of the Tuscany region.

1. Introduction

One of the most important environmental issues related to the use of geothermal fluids to generate electricity is the emission of non-condensable gases to the atmosphere. Vent stacks from geothermal plants emit carbon dioxide (CO_2) and methane (CH_4) causing concern because of their role as greenhouse gases (Bloomfield and Moore, 1999; Bloomfield et al., 2003), despite those emissions are quite small compared to carbon and fossil fuel plants, indicating that the contribution of these sources is practically negligible (Miller and Van Atten, 2004). Geothermal power plants also emit hydrogen sulfide (H_2S) in relative high amounts (Peralta et al., 2013), since H_2S is one of the main constituents of the geothermal fluids, after H_2O and CO_2, and it is released into

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the atmosphere as waste pollutant of the entire productive cycle. The presence of H_2S in the air, and then in water, (Olafsdottir et al., 2014), soils and vegetation is one of the main environmental concerns for the areas that host geothermal fields.

The increase of geothermal energy production, and the consequent release of pollutants, such H_2S, has sometimes raised the opposition of the nearby living population, for example, at Puna, Hawaii (Anderson, 1991). The environmental impact, was also one of the reasons for which the population of Milos (Greece) obtained the stopping of geothermal energy production on the island (Marouli and Kaldellis, 2001). Some studies, in different geothermal districts, have been performed in order to evidence, at a sub-regional or local scale, the potential impacts on the environment of the H_2S and other trace elements (notably, mercury and arsenic) by the operation of geothermal power plants (Bargagli et al., 1986; Noorollahi, 1999; Bacci et al., 2000; Kristmannsdóttir et al., 2000; Loppi, 2001; Gunnarsson et al., 2013; Peralta et al., 2013). Furthermore the H_2S toxicity for humans is a proven fact at certain concentrations (WHO, 2003), and the unpleasant odor, even at very low concentrations, can be detected far away from the emission points (Thorsteinsson et al., 2013).

In this study the dispersion into the atmosphere of the H_2S has been tested in order to evidence, via numerical code and GIS tools, coupled with field measurements, the possible impacts of the H_2S emission on the inhabitants living close to the geothermal power plants belonging to the Tuscany geothermal districts. With this aim, we used a geomatic approach dedicated to data processing of geographic information necessary to run the code and to manage the outputs, and a mathematical approach, represented by the numerical code DISGAS (Costa et al., 2005; Granieri et al., 2013, 2014, 2015), for modelling the H_2S plume dispersion, starting from the stack emissions and the local meteorological conditions. The numerical code, we used, allows the definition of H_2S same-concentration lines, in the air, at different heights from the soil, representing a powerful instrument to identify the areas of the domain preferentially affected by the presence of H_2S, in function of the prevailing winds and hydrodynamic conditions of the atmosphere. DISGAS code, moreover, could yield a reliable prediction of H_2S pollution in case of unexpected events, in view of the impact of future expansions of the geothermal energy production through new wells or new power plants.

2. Background

2.1. Features of H_2S and effects on the human health

Hydrogen sulfide is a colorless water-soluble gas, with a characteristic odor of rotten eggs and defined for this putrid gas. Its origin may be natural, (about 90% of the total H_2S in the atmosphere, US Environmental Protection Agency, EPA, 1993) as gas species produced by anaerobic bacterial reduction of sulfur-containing animal and vegetable proteins and as gas released from volcanoes and geothermal areas (Aiuppa et al., 2005); but also anthropogenic, as product of industrial activities (Bates et al., 1992). The artificial origin of hydrogen sulfide derives from the production process of coking coal, cellulose (method with Kraft), fertilizers, dyes and pigments, refinement of crude petroleum, tanning of hides and skins, treatment of waste water.

Background concentrations of H_2S in ambient unpolluted air have been estimated to be between 0.14 and 0.4 μg/m^3 (US EPA, 1993), whilst the typical concentration in urban area is about one order of magnitude higher (1.0–3.0 μg/m^3, Kurtidis et al., 2008). High air levels of H_2S are measured near waste-water treatment plants, oil refineries, and landfills (from a few units to a few tens of mg/m^3, WHO, 2003) as well as in volcanic and geothermal areas, where H_2S is likely formed by water-rock interaction, which is accelerated by the high heat gradient induced by the presence of a cooling magma body. In these environments, the H_2S is released in the atmosphere by hot vents and hot springs. In some sites of the quiescent Colli Albani volcano (Italy), Carapezza et al. (2012) found a H_2S air concentration > 700 mg/m^3 which represents an immediately lethal value.

Because H_2S is a gas, human exposure is principally via inhalation, and the gas is rapidly adsorbed through the lungs. Health effects include respiratory, ocular, neurological, and metabolic effects and the death after single exposures to concentrations ≥700 mg/m^3 (WHO, 2003). A summary of these effects is presented in Table 1 and hereafter discussed. H_2S is felt by humans at very low concentrations with a reference odor threshold equal to 0.011 mg/m^3 but becomes odorless at concentrations higher than 140 mg/m^3 (WHO, 2003) and, to values close to those lethal (≥700 mg/m^3) it has an odor almost pleasant. Inhalation of 2.8–14 mg/m^3 does not affect respiratory function in healthy men and women but lack of vigor, common ailments and states of agitation are common symptoms for elderly, young children and asthmatic individuals (WHO, 2003). In New Zealand, about 70% of workers exposed to daily concentrations than often exceeded 28 mg/m^3 complained of fatigue, loss of appetite, headaches, irritability, memory lapses, dizziness. At concentrations >140 mg/m^3, olfactory paralysis occurs, causing a loss of odor perception; this makes H_2S very dangerous because one or two breaths at concentrations ≥700 mg/m^3 can be fatal (the so-called "slaughterhouse sledge-hammer" effect). Table 2 shows the allowable thresholds concentration in the air according to the guidelines of the World Health Organization (WHO) and regulations in the countries that cultivate geothermal fields (e.g., New Zealand and Iceland). In fact, the presence of H_2S is always verified in geothermal areas and in the vicinity of geothermal plants since H_2S is one of the main constituents of the geothermal fluid. In particular it can be released into the atmosphere from natural geothermal manifestations (fumaroles, hot springs, geysers, soils degassing), as well as from conventional geothermal plants in case of exploitation of the underground resource as better explained in the following section.

Soils may adsorb considerable amounts of H_2S from the air, retaining most of it as elemental sulfur (Cihacek and Bremner, 1993) but preferentially H_2S is oxidized by molecular oxygen and hydroxyl radicals of air (Davis et al., 1979), forming sulfur dioxide (SO_2) and ultimately sulfates (Hill, 1973), with a residence time in air typically <1 day. Sulfur dioxide and sulfates compounds are removed from the atmosphere through absorption by waters, plants and soils or through wet precipitation. The sulfur-containing compounds can cause fish deaths, while the effect on plants is related to a persistent removal of trace elements essential to the functioning of their enzymatic systems (Luther et al., 2004).

2.2. General functioning of a geothermal plant and geothermal plants in Tuscany

A geothermal power plant uses the hot pressurized fluid of the underground to generate electrical energy (DiPippo, 2016). The geothermal fluid is basically composed by dry steam or, more frequently by hot water and steam but always with a significant amount of gases

Table 1
Human health effects resulting from exposure to H_2S (WHO, 2003).

Exposure (mg/m^3)	Effect/observation
0.011	Odor threshold (geometric mean but depending on the individual)
2.8	Bronchial constriction in asthmatic individuals
5.0	Increased eye complaints
7.0–14.0	Increased blood lactate concentration, decreased skeletal muscle citrate synthase activity, decreased oxygen uptake
5.0–29.0	Eye irritation
28.0	Fatigue, loss of appetite, headache, irritability, poor memory, dizziness
>140	Olfactory paralysis
>560	Respiratory distress
≥700	Death