Air Quality Planning for Geothermal Development

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The Geothermal Industry and Air Quality

Geothermal power plant development is a long and expensive process which starts with geological exploration and is completed when the power plant is on line generating power. Subsequent power production with associated replacement well development, plant and well field maintenance, and unplanned plant upsets may be 30 to 50 years in duration. Each geothermal development and power production activity has air quality issues associated with it.

All to often the air quality aspect of geothermal facilities is not dealt with in a preplanned logical fashion, but is lost in the maze of engineering and financial concerns facing a developer or an operator of a geothermal power plant. Environmental issues, such as air quality, are generally not taken into consideration until after the decision is made to proceed with development. Consequently, the lack of environmental data and established environmental assessment and mitigation plans can cause delays in permitting, which in turn can cause delays in obtaining project financing. Similarly, responding to regulatory citations or public complaints once development or power production is occurring can cause delays and negatively impacts the corporate environmental image.

Historically, air quality has represented a dichotomy for the geothermal industry. While air quality impacts from geothermal facilities are almost always small, public and regulatory concerns have often been high. This appears to be due to the facts that the major pollutant, hydrogen sulfide (H_2S), has an extremely low olfactory threshold and that the enrichment of specific toxic pollutants such as mercury, radon, and arsenic in geothermal areas is widely known. Secondary issues have been nitrogen oxide emissions from large drill rig diesel engines, particles originating from dust, and generic cooling tower air quality and visibility impacts. The fundamental air quality challenge for the geothermal community has been to control H_2S emissions and to demonstrate that these controlled emissions along with the emissions of other toxic pollutants are small and represent negligible environmental and human health impacts.

Experience has shown that strategic air quality planning during the planning phases of plant and well field design can reduce costs and delays during the licensing process, reduce human health and environmental impacts, and can ameliorate public concerns over perceived environmental issues. The key to a cost-effective and streamlined approach is the gathering of data early in the process, even including collecting some data in the exploration phase, and using standard and well established procedures for assessing air quality impacts.

With regard to geothermal development, an educated mind is often an open mind. Documenting air quality and educating the public and regulatory agency staff should be initiated early-on and made integral to the permitting process, because regulators and the public typically have a limited understanding of geothermal well field and power plant operations. Also, the high turn-over rate with in some regulatory agencies may necessitate bringing new personnel up to speed on geothermal operations. Educating regulatory personnel on geothermal operations increases their ability to make timely decisions. Similarly, educating community leaders helps them to lead the public's attitudes and comments to a positive result. It needs to be continually emphasized to all parties that the air quality impacts from a properly managed geothermal facility are small.

The intent of this paper is twofold. First, it presents an item by item discussion of air quality topics which are relevant to both the development and plant operation phases of the geothermal industry. Second, it presents the strategies for fast track air quality data collection and evaluation designed to minimize delays in the licensing process. The latter can be of significant financial importance, particularly when the time value of the employed capital in well field development and construction is considered.

Baseline Air Quality

As with any industrial development, the documentation of background or baseline air quality is essential for a geothermal project. Total atmospheric concentrations of specific pollutants can be compared with regulatory standards or recognized environmental and health threshold levels by adding baseline levels to predicted impacts from the project. In addition to providing information needed for project permitting, good baseline data allows the relative fraction of air pollutant levels attributable to geothermal development to be separated from those that are not, if the project is suspected of creating problems at some point in the future.

In some cases and for some pollutants, background estimates can be made based on monitoring already done by government agencies or done in support of other industrial activities in the vicinity of the geothermal project. However, in many cases and for many pollutants, quality representative data will not be available. Often data from the closest sites may be from highly urbanized or industrialized areas in the region where there has been monitoring conducted for the very reason of their poor air quality. It should also be remembered that a baseline condition unique to geothermal sites is the presence of natural geothermal and volcanic vents and fumaroles. When quality representative data are not available, conservative (high) estimates are frequently the only data that can be made defensible.

Site-specific monitoring and sample collection provides the most definitive baseline data. Due to seasonal cycles in atmospheric conditions, routine and periodic sample collection or monitoring over the course of at least one year is recommended. However, even limited grab samples can provide useful information. For example, numerous mercury and radon soil gas measurements are often made as part of geothermal exploration. The inclusion of a few atmospheric samples in the sample set would provide the information needed for estimating their atmospheric baseline levels at very low incremental costs. A number of different passive, battery-powered and AC-powered samplers or monitors can be deployed during the exploration phase to obtain pollutant baseline data. Early collection of these baseline data in the exploration phase will help facilitate project licensing

Emission Inventory

Before an assessment of air quality impacts can be made, an emission inventory must be developed. An emission inventory is a listing of both long-term (generally annual) and short-term (generally hourly) emission rates for each relevant pollutant from each emission point. Emission categories common to all geothermal projects include well venting, drill rig diesel engines, and fugitive dust sources. Additional emission points for flash-steam and dry-steam technology plants include plant silencers, sulfur plant exhaust, and the cooling tower. For binary plants, emissions from a cooling tower (if present — in some cases an air cooled condenser may be used) and from the use of a secondary volatile fluid (e.g., freon or isobutane) need to be estimated. Emission rates are necessary for input into air dispersion modeling used to predict impacts and emission rates are often the basis of an air permit, which may stipulate both short-term maximum and long-term average emission levels.

In developing an emission inventory, operational scenarios need to be taken into consideration, control efficiencies need to be documented (viz, for the sulfur plant), and the resource chemistry needs to be defined. Different operational scenarios will cause different emission rates, even during a given phase of the geothermal project. For example, during well field development, which may be two to three years in duration, the total number of wells projected to be drilled and vented may be different for each year and hence the annual emission inventory will be different for each year. During the normal plant operation phase, which may be 30 to 50 years in duration, the number and frequency of replacement wells that will be drilled may vary from year to year. Also, the frequency and duration of upsets tends to decrease after the initial "shake down" year of operation and the length and duration of routine maintenance periods may increase with the age of the facilities.

Resource chemistry is fundamental in the development of emission inventories. Fluid and gas samples should be collected for every well that is tested during the exploration phase. At least one set of samples should be collected from each and evaluated by a third party contractor or at minimum chemical analyses should be completed by a third party laboratory. Samples of liquid and gas from wells should be analyzed for all parameters used in the air quality evaluation regardless if they are expected to be present or not. Nondetectable below a low and quantifiable detection limit is one of the best results one can obtain. A typical well test chemical sample suite should be designed to provide not only resource and engineering parameters but also be designed to provide adequate data for the air quality evaluation. An air quality specialist needs to be involved in this process because traditionally the testing of resource chemistry is somewhat different than what is appropriate for emission inventory development. In some cases the chemical form of the pollutant is important. For example, knowledge of the chemical form of mercury and boron in the geothermal fluids is needed to estimate their partitioning between particulate and gaseous phases and their fate and transport through the geothermal facility and in the environment. The "bottom line" is that the emission inventory data used in impact assessment and permitting is only as accurate as the quantification of the pollutants contained in the geothermal fluids.

Impact Prediction

Impact prediction is usually accomplished with dispersion modeling. Dispersion models developed by the U.S. Environmental Protection Agency (EPA) are widely used, are in the public domain, and are credible. While there are a number of different EPA models available, probably the most widely used and relevant for the geothermal industry are the Industrial Source Complex (ISC) model for the prediction of atmospheric impacts from point sources (well and plant silencers, sulfur plant stack, cooling tower and diesel engine exhaust), a visibility impact screening model (VISCREEN), and a fugitive dust model (FDM).

Each of these models can be run with worst-case meteorological scenarios. However, the use of on-site meteorological records representing a least one year of data provides more realistic and generally less conservative (lower) impact predictions than are obtainable from using worst-case meteorological scenarios. Establishing a meteorological station is one of the first on-site activities that should be conducted, so that one year of meteorological data will be available for modeling. This inexpensive, but critical, task is often overlooked by developers who find out later that development has to wait until adequate meteorological data is collected or that permitting is more difficult due to the high values that worst-case meteorology produces when used in a dispersion model.

Siting and operational criteria for meteorological stations that collect data for use with dispersion modeling are specific. They include distance and height of nearest obstructions, height of tower, and auditing procedures. Key meteorological parameters are wind speed, wind direction, temperature and relative humidity.

Besides emission factors and meteorology, stack physical parameters, topography and nearby obstructions are input into dispersion models to predict impacts. Their accurate documentation is essential and the awareness of their effects on impacts can be taken into consideration in the planning phase. Discharge temperature, total flow rate, enthalpy, the noncondensable gas content, stack height, stack diameter, height of nearby buildings, and the forest canopy height adjacent to a drill pad all influence predicted air quality impacts. By being aware of these parameters, minor changes can be made in stack dimensions and orientation or discharge point locations with respect to topography in order to reduce predicted impacts at sensitive receptors.

The selection of the receptor points at which air quality impacts will be predicted and eventually perhaps monitored is not based solely on technical considerations. Community concerns, public access, and ecological settings are important factors in the selection of sensitive receptors. Generally, air quality standards need to be met in ambient air. The definition of “ambient” varies among air quality agencies, but is usually defined as air at property boundaries, at the plant fence line, at the nearest point where the public has access, or air external of buildings. None of these definitions are appropriate for geothermal facilities, which are often on leased public lands with many acres of well fields. The ramifications of lease boundaries, nearest residences, roads, recreation sites, etc. should be taken into consideration in the planning process. It is not an uncommon practice (and often the most cost-effective) for an industrial developer planning a new facility to purchase nearest residences, purchase right-of-ways, and/or negotiate with public agencies for the gating of roads during critical time periods (this might be well testing for the geothermal industry) as a solution to air quality issues.

Impact prediction includes the calculation of average atmospheric concentrations of pollutants in time frames commensurate with those of environmental and health based standards and thresholds. The most common time frames are one hour, twenty-four, and annual. Atmospheric concentrations also provide the basis for calculating deposition impacts, for example, mercury in a watershed. The significance of odor and visibility impacts is reported in terms of human perception.

Frequently, the mathematics and atmospheric physics behind the gaussian modeling needs to be explained in general terms. Air quality impact reports tend to very technical presentations of complex mathematical models. Tables that present data can often be misinterpreted by those who may perceive that any number greater than zero is a negative impact. The modeling results may show that impacts from geothermal development are several orders of magnitude lower than regulatory standards or that the probability and frequency of occurrence of high values is very small, but the significance of this information is lost because it is buried within a complex report. Summaries that explain the results in understandable terms should be provided at the front of the reports and tables should show results in comparison with the regulatory thresholds.

In addition to demonstrating regulatory compliance, impact prediction by dispersion modeling is also useful in the planning phases of geothermal project. The effects of alternate power plant and well pad sites on the air quality at various receptors can be assessed. Similarly the control efficiencies needed during well venting, through the sulfur plant or during upset conditions to avoid unacceptable air quality can be determined.

Source Testing

Obtaining emission inventory data from existing geothermal power plants with similar technology as the proposed project is often useful in developing an emission inventory or in demonstrating to a regulatory agency that a specific control efficiency can be achieved for a given proposed technology. However, the most definitive way to develop an emission inventory or to demonstrate control efficiencies is to conduct actual measurements on each discharge point. Periodic source testing is also often a condition of air quality permits. As previously discussed, at a minimum the resource chemistry needs to be quantified by testing well venting. While resource chemistry provides the basis for estimating emissions from downstream discharge points for flash-steam and dry-steam technology plants, actual source measurements provide more accurate information. By measuring emissions, for example, from an existing H_2S control system stack, its H_2S control efficiency, the transport of other pollutants through the system, and the chemical form of pollutants (e.g., mercury) can be quantified rather than estimated. Standardized protocols for conducting source testing have been published by the EPA in the Code of Federal Regulations and in numerous guideline documents. These protocols even include specifications for the position and size of sampling ports, which, along with access provisions, should be part of the plant design to minimize unnecessary and expensive future modifications. In addition to protocols for testing point sources (well venting, plant silencers, liquid redox stack, cooling tower and drill rig diesel engine exhaust), protocols have been developed by the EPA to estimate emissions from fugitive emissions of volatile organic compounds (VOC) from valves, flanges, etc., by using hand held survey equipment. These protocols are useful in estimating VOC emissions from a binary plant.

Cooling Towers

The impact to air quality and visual resources from cooling tower plumes is generic to many types of utilities and industries. In addition to EPA models which can predict by dispersion air quality impacts, there are models which allow cooling tower plume dimensions and plume drift to be calculated from meteorological conditions and cooling tower characteristics. One such model has been developed by the Electric Power Research Institute (EPRI) and is called the Seasonal and Annual Cooling Impacts (SACTI) model. Most air quality permits do not require a cooling tower plume dimension model or a plume drift model. However, the aesthetics portion of environmental assessments does require the plume dimension information for the prediction of the visibility of the cooling tower plume from critical view points such as residences, scenic overlooks and by-ways. Plume drift analysis is also often part of environmental assessments due the potential impact on nearby vegetation and surface waters.

Plume drift is the fallout of large water droplets which are entrained in the exhaust of cooling towers. The fallout of water droplets is of concern, because they contain dissolved chemicals. These chemicals are salts (e.g., sulfates and chlorides), trace amounts of toxic compounds (boron, arsenic and mercury), and biocides added to the cooling tower to control algae and bacteria. While the exact impact radius depends on cooling tower parameters and meteorological conditions, generally most plume drift impact occurs within 500 meters of the cooling tower. Prevailing wind directions and the nearest sensitive receptors need to be taken into consideration when the location of the cooling tower is specified.

Fugitive Dust

The impact of fugitive dust can be predicted by the EPA's Fugitive Dust (FDM) model. Fugitive dust is produced by wind erosion of barren soil, construction and demolition activities, and vehicular traffic. About 50% of all particles (by mass) suspended in the air from soil and road dust are less than 10 microns in aerodynamic diameter (PM_{10}) and about 5% are less than 2.5

microns ($PM_{2.5}$). Both PM_{10} and $PM_{2.5}$ are U.S. federal pollutants. There are also many local statutes for nuisance dust or Total Suspended Particles (TSP). The EPA has published guideline documents for the calculation of fugitive dust emission factors. The silt content (less than 200 mesh size fraction) of the soil or road dust is used in the emission factor equations. Soil surveys are available for identification of soil types in many areas and in some cases these soil surveys provide the typical silt content of the soils. Even if the silt content data are not available, the soil surveys can be used to identify the locations for sample collection of material that can undergo size analysis and subsequent emission factor calculations. The chemical analysis of the less than 400 mesh size fraction (< 38 microns) provides a good approximation of the chemical makeup of the suspendable fraction of road dust and soil. This is important because the transport of toxic metals with soil and road dust can be of concern, particularly from highly mineralized soils such as can be found near geothermal resource areas. The precipitation and wind speed characteristics of a site, anticipated traffic counts, and mitigation measures (watering, soil stabilizers, vehicle speed limits, etc.) can be factored into the calculation of emission rates. As with the prediction of impacts from point sources, the predication of potential fugitive dust impacts allows for the evaluation of various control scenarios in terms of cost and effectiveness to be conducted during the planning phase of the project.

Drill Rig Diesel Engines

The nitrogen oxide emissions from large drill rig diesel engines are an air quality issue. There are several nitrogen oxide compounds. Among the nitrogen oxide compounds, only nitrogen dioxide (NO_2) is a federal criteria pollutant for which there are federal and local air quality standards. It is also quite toxic and NO_2 is the only nitrogen oxide gas that absorbs light and can decrease visibility. About 10% to 20% of the nitrogen oxide emissions from diesel engines are in the form of NO_2 with the remaining being nitric oxide (NO). Nitric oxide is oxidized in the atmosphere to NO_2. The amount of NO that is oxidized to NO_2 is dependent on the amount of oxidants such as ozone that are in the atmosphere. In remote nonurbanized locations, ozone concentrations are low, which limits the formation of NO_2. The calculation of the amount of total nitrogen oxide that is in the form of NO_2 in remote nonurbanized areas is referred to as "the ozone limiting method." The ozone limiting method can provide estimates of atmospheric NO_2 that are favorable for geothermal development. The nitrogen oxide emission factors compiled by the EPA for generic diesel engines are higher than those that have been obtained from actual source tests on specific drill rig diesel engines, consequently source testing is recommended in the permitting process. Short-term impacts of NO_2 from drill rig engines, not average annual impacts, are the pivotal environmental issue since multiple engines may be operating for a short period on more than one well site at a time. Institutional controls on the location and the number of engines that can be operated simultaneously is a strategy to avoid permitting road blocks. There are technical nitrogen oxide control approaches, but they are not very satisfactory due to cost and/or their impact on the lifetime of the diesel engines. Two common approaches are spark retardation and the use of ammonia injection. Diesel engines emit other pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), particles and hydrocarbons. However, their impact levels have typically not been high enough to warrant environmental or permitting concerns. The SO_2 emissions can be estimated from the sulfur content of the diesel fuel, which is limited in many jurisdictions. Ironically, in many airsheds the levels of nitrogen oxide emissions from mobile diesel sources (trucks, buses, trains and construction equipment) are dramatically higher than that from a small number of drill rig engines. However, because drill rig engines are considered a stationary source, most air quality authorities require an evaluation for permitting their operation.

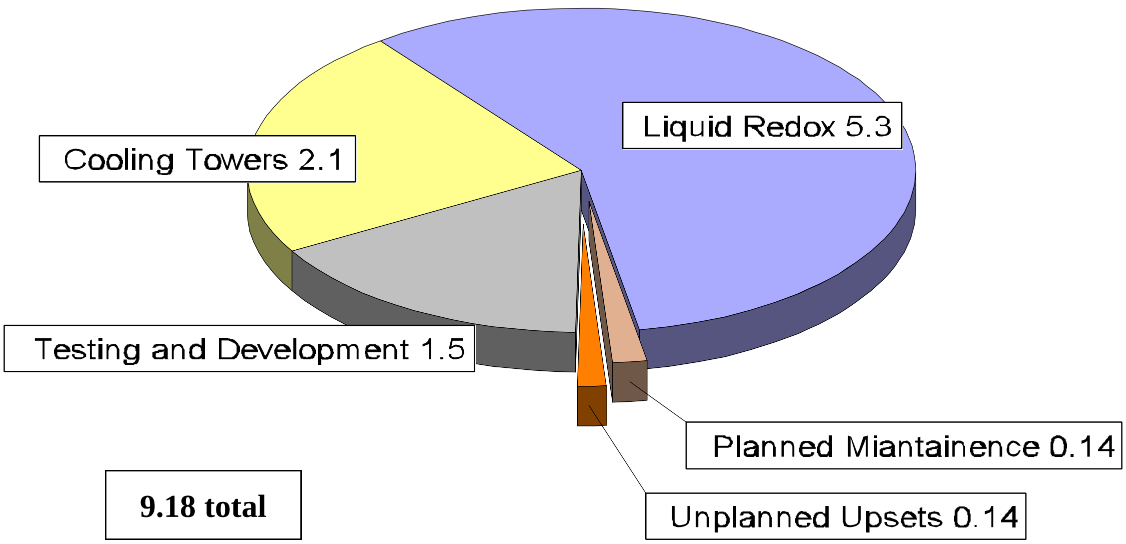
Ambient Monitoring

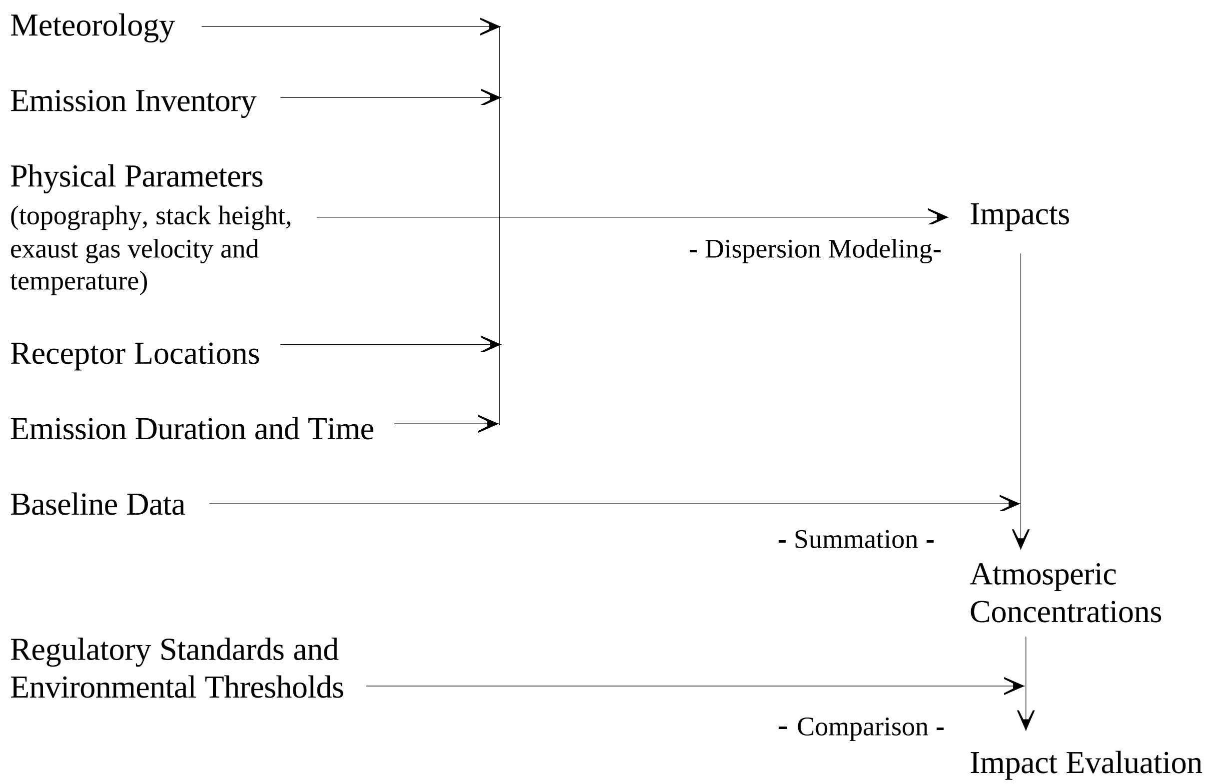
Once well field development and plant operation are under way an ambient monitoring program for H_2S and meteorology is generally appropriate and serves as an integral part of an odor control program or to demonstrate compliance with local H_2S standards. To provide continuity of data and to control costs, the continued operation of the meteorological station set up for baseline data and impact prediction is a good strategy and the long-term operation of the meteorological station should be taken into consideration when it is initially setup. Standards and nuisance odor thresholds for H_2S are both low and quality instrumentation is required to provide stable credible results in the part per billion (ppb) range that is needed. The California one-hour standard is 30 ppb and the olfactory (odor detection) limit is about 4 ppb for most people. The use of an EPA reference sulfur dioxide (SO_2) monitor with an in-line SO_2 scrubber and H_2S to SO_2 oxidizer is a approach often used and can provide real-time detection of less than 1 ppb H_2S. Because SO_2 is a federal criteria pollutant and is a major pollutant from fossil fuel combustion, the siting, operation, and data reduction associated with SO_2 monitoring has been well documented and published in the Code of Federal Regulations. In addition, SO_2 monitoring systems are "off-the-shelf" technology. Both state-of-the-art meteorological and H_2S (modified SO_2) monitoring systems can be operated via modem so that they can be remotely followed on a real-time basis or interrogated to retrieve stored data. The ability to follow wind conditions and H_2S concentrations on a real-time basis offers considerable flexibility in controlling H_2S impacts during well testing or plant upsets. The storing of hourly H_2S and wind data also provides the documentation of impacts should odor issues be raised.

Summary

A visible cooling tower steam plume and a detectable H_2S odor are obvious off-site environmental manifestations of a geothermal facility. Coupled with concerns about exposure to the high toxicity of mercury and arsenic along with radiation from radon, they have historically been to a large part responsible for the perception that air quality is significantly impacted by geothermal activities. In reality air quality impacts from geothermal facilities are usually small, particularly as compared to many other industries or fossil-fuel power plants. If a well thought out air quality program is an integral part of geothermal development and plant operations, air quality concerns can be addressed and delays in licensing can be avoided. Key to an air quality program is the early collection of data, the development of a well field and plant operational scenarios with consideration of future air quality and an aggressive educational program.

Permitted Annual Hydrogen Sulfide Emissions for a Geothermal Power Plant (metric tons)





Key Air Quality Action Items

- On-Site Meterological Monitoring
- Baseline Air Quality
- Resource Chemistry
- Plant and Well Field Plan of Operations
- Selection of Sensitive Receptors
- Topography and Property Boundaries
- Dispersion Modeling
- Regulatory Requirements and Standards
- Public and Agency Education