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Mitigation and Calculation of Short-term Hydrogen Sulfide and Nitrogen Dioxide Impacts to Ambient Air Adjacent to Geothermal Well Pads

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Abstract

The impact of hydrogen sulfide (H_2S) from well venting, and the impact of nitrogen dioxide (NO_2) from drill rig diesel engines, to ambient air adjacent to well pads are typically the two most significant air quality issues associated with geothermal development. The traditional use of abatement chemicals to mitigate H_2S impacts and of reductive catalysts or ignition retardation to mitigate NO_2 impacts are costly and have other environmental "side effects." The use of appropriately designed well silencers and drill rig engine exhaust systems can reduce the need for these undesirable and costly control options.

Another cost-effective mitigation strategy is based on an iterative meteorological monitoring approach. By correlating ambient air impacts with meteorological conditions, the use of abatement chemicals can be limited to only those time periods that will cause unacceptable pollutant levels. Impacts and meteorological conditions can be correlated by analysis with the standard, regulatory-based U.S. Environmental Protection Agency ISC3 dispersion model.

In regards to the NO_2 impact from drill rig engines, accurate emission data are useful in that only a small fraction of the total nitrogen oxides (NO_x) emitted from diesel engines are in the form of NO_2, most is in the more benign nitric oxide (NO) form. (Source tests often only provide a total nitrous oxides value reported as NO_2 or an estimate of the NO_2 fraction.)

Finally, an understanding of site-specific atmospheric chemistry and physics is very important for drill rig engine impact assessment, since NO is oxidized to NO_2 by oxidants (viz., ozone) in the atmosphere. Unlike the typical assessment of NO_2 impacts from most industrial sources, consideration of the transit time of exhaust gases from drill rig engines to reach the points of

ground-level impacts is very important for calculating NO_2 levels and for the demonstration that NO_2 levels are lower than may otherwise be predicted. Because the exhaust height from a drill rig engine is relatively short as compared to most industrial “smoke stacks,” the transit time for the exhaust gases to reach ground-level impact points are shorter and there is less time for NO to chemically react with atmospheric oxidants to form NO_2.

Introduction

Ambient air is defined by federal regulations as, “that portion of the atmosphere, external to buildings, to which the general public has access” (40 CFR 1995). Most state and local air quality authorities define ambient air in an analogous fashion or by reference to the federal definition. From this definition, it has generally been concluded that in a regulatory sense ambient air does not include the atmosphere over land owned or controlled by the source and to which public access is precluded by a fence or other physical barriers. Stated another way, except for some unusual exceptions, ambient air starts at the fence line at or within the property or leasehold boundary. The definition of ambient air is important because that is where air quality standards must be met.

For geothermal development the most difficult air quality standards to comply with are short-term (e.g., one-hour average) hydrogen sulfide (H_2S) and nitrogen dioxide (NO_2) standards since geothermal resources contain the noncondensible gas H_2S and, in regards to NO_2 emissions, as many as four large diesel engines with horsepower ratings which can exceed 900 BHP can be used simultaneously in the well drilling process. While there are no federal H_2S or short-term NO_2 standards, there are short-term state and local H_2S and NO_2 standards. For example, of special significance for the geothermal industry, the state of California has promulgated one-hour average H_2S and NO_2 standards. The California one-hour average standard values are 0.03 ppm (42 $\mu g/m^3$) for H_2S and 0.25 ppm (470 $\mu g/m^3$) for NO_2.

Hydrogen sulfide from well venting through silencers and nitrogen dioxide from drill rig diesel engines can impact ground-level ambient air close to their point of discharge before dilution by dispersion occurs due to the fact that in comparison with typical industrial “smoke stacks,” the height of well silencers and of skid-mounted diesel engines exhausts are low. The combined effect of this low height and the fact that ambient air can be encountered, in a regulatory sense, as close as the edge of the well pad that have dimensions typically of no more than several hundred meters is that one-hour average standards can be exceeded in ambient air. Topographical highs in the vicinity of a well pad exacerbate the impact.

Traditionally, abatement chemicals such as sodium hydroxide or hydrogen peroxide have been added to well silencers during venting to mitigate H_2S emissions. Both of these common chemical abatement approaches are costly, have byproducts that must be disposed of, and represent an occupational hazard in their handling (Hirtz and MacPhee 1989). The two most common approaches to reducing NO_x emissions from diesel engines are ignition retardation and ammonia injection catalytic reduction. Ignition retardation requires more engine maintenance and increased emissions of carbon monoxide and hydrocarbons are concomitant with decreased NO_x emissions. Ammonia injection catalytic reduction is very costly and ammonia represents an occupational hazard in its handling.

Silencer and exhaust system designs which reduce impacts of H_2S and NO_x from well venting and drilling, respectively, are presented here. They are based on analyses conducted for actual well pads and the geothermal resource chemistry at the proposed Telephone Flat geothermal development project located in the Medicine Lake highlands of California (U.S. Dept. of Interior, et al.1999). In addition, an procedure to mitigate H_2S impacts by conducting real-time meteorological monitoring and a discussion on the method for calculating the extent of the atmospheric conversion of NO to NO_2 appropriate for drill rig diesel engine emissions are presented. Actual atmospheric, meteorological and topographic conditions have been used to generate the data.

Mitigation and Calculations of H_2S Impacts from Well Silencers

The impacts of H_2S from well venting were predicted adjacent to well pads with the U.S. Environmental Protection Agency ISC3 dispersion model (U.S. EPA 1995). Two years of on-site meteorological data collected 2.3 km from the proposed power plant site were used for the modeling. The hydrogen sulfide content characteristic of the resource, its total gas composition (steam plus noncondensible gases) and the projected production rates of the wells that were used in the modeling were estimated from existing wells at the site. Table 1 shows the highest one-hour average H_2S concentration in ambient air at the point of maximum impact from wells located on each the project's 14 well pads and the percentage of hours annually that the California one-hour standard of 42 $\mu g/m^3$ would be exceeded by the wells on each pad. The predicted impacts from both the standard 30 foot high silencer and a silencer extended an additional 30 feet are included in the table. Table 2 shows the number of one-hour periods that the California standard would be exceeded from the wells during different times periods over the course of a year.

Two key observations can be made in reviewing the data in Tables 1 and 2. These are: 1. Lower and less frequent impacts above the California standard occur when the taller silencer is used as compared to the standard-sized silencer. , and, 2. The high impact events do not occur uniformly over the course of the year but are more frequent during the late fall, winter and early spring. The former observation is reasonable since the concentration of H_2S becomes more dilute (the plume is more dispersed) before reaching the maximum impact point when a taller silencer is used. The second observation is reasonable due to the fact that the atmosphere is more stable at the Telephone Flat site during the late fall, winter and early spring and under those conditions there is less mixing of the plume before it impacts the ground near the well pad. It was also observed in reviewing modeling data, that for some wells, impacts above the California one-hour standard only happen when the wind is from a limited arc of direction. This occurs when there is an isolated topographic high adjacent to the well pad and there is a wind-directed impingement of the plume on it. For example, modeling of the impact from a well on one well pad at the project site (Conditions modeled are not showed in Tables 1 and 2.) revealed that there were 99 hours over the course of the year that the California standard would be exceeded. Every one of those hours was when the wind was blowing from the compass directions between 45° to 135°.

The practical implication of these observations is quite simple. By accurately predicting impacts by modeling and by understanding what physical and meteorological conditions combine to cause the air quality standard exceedences, the amount of abatement chemicals used and the frequency of their addition can be minimized and in some cases avoided altogether. Adjustment of silencer dimensions, a program for real-time meteorological monitoring and the avoidance of well venting at certain times of the year are relatively inexpensive alternatives to a chemical abatement program.

Mitigation and Calculations of NO_2 Impacts from Drill Rig Diesel Engines

The impacts of NO_2 from drill rig diesel engines were predicted by dispersion modeling. As with the H_2S from well venting, the U.S. EPA ISC3 dispersion model with two years of on-site meteorological data were used. Unlike H_2S, which will generally have a negligible background concentration, NO_2 is ubiquitous and may occur at appreciable background levels. A background estimate (1.9 $\mu g/m^3$) of atmospheric NO_2 was made for the site and added to the impacts predicted by modeling. Exhaust gas physical and chemical parameters were obtained from actual source tests of Caterpillar D398 engines. From the source test data it was calculated that approximately 10% of the total nitrogen oxides were in the form of NO_2 (90% NO and 10% NO_2). There are two sources of NO_2 which cause impacts to ambient air from the operation of drill rig engines. These are the direct emission of NO_2 (10% of the total NO_x emitted) and the oxidation of the NO (90% of the total NO_x emitted) to form NO_2 in the atmosphere. The amount of NO that is oxidized to NO_2 before the plume reaches the ground is dependent on the amount of oxidants (viz., ozone) that are in the atmosphere and the transit time of the plume before it reaches the ground-level impacts points. Estimates of the ozone background (0.018 ppm) were obtained from data collected in Yreka, California (Calif. EPA 1996). The effect due to the short transit time of gases from the relatively short diesel exhaust “stacks” to ground level impact points were estimated following kinetic theory that has been published for NO in a plume environment (Chu and Meyer 1991, Cole and Summerhays 1979, Peters and Richards 1977, Shu et al. 1978, and Sverdrup et al. 1982.). It should be noted that the reduction in the total amount of NO oxidized to NO_2 due to the short atmospheric residence time (i.e., equilibrium is not reached) characteristic of diesel engines used on well pads is not a calculation commonly done since for most taller industrial smoke stacks the transit time is long enough before ground level impact that equilibrium between NO and atmospheric oxidants is obtained. Without taking the short transit time into consideration the NO_2 impacts are over predicted for drill rig diesel engines.

Nitrogen dioxide concentrations at maximum impact points for various exhaust system designs and methods of calculating atmospheric NO to NO_2 oxidation are provided in Table 3. The data in Table 3 are for four engines operating simultaneously at 100% load and 1200 rpm. As can be seen in the data shown in Table 3, by manifolding the exhaust from all engines together there is a dramatic reduction in the predicted impacts. Similarly, smaller but significant reductions can be realized by increasing the stack height beyond the standard 13.5 ft horizontally discharged exhaust systems. The dramatic reduction achieved by manifolding all four engines together is due to the increase in a parameter referred to as “effective stack height.” Effective stack height is the sum of physical height of the stack and the height the plume rises vertically after it leaves the stack. By increasing the upwards velocity of the gas leaving the stack and most importantly by increasing the mass of hot gas which will rise due to its buoyancy as compared to the cooler surrounding atmosphere the effective stack height is increased substantially by manifolding the exhaust together into one discharge point.

The effect of calculating the atmospheric NO to NO_2 conversion in three different ways is also shown in Table 3. Unquestionably, taking the concentration of atmospheric ozone and the kinetic effect into consideration is the most correct theoretical method for the calculation of atmospheric NO_2 concentrations. However, since accurate concentrations of ozone and an understanding of transit times are required, the calculation of NO_2 concentrations assuming all NO is converted to NO_2 and by the ozone limiting method alone (equilibrium with atmospheric oxidants) are provided in Table 3 to allow for a comparison of the magnitude of the refinements in calculations.

As with H_2S from well silencers, the practical implications of understanding meteorological, physical, and atmospheric parameters that influence the NO_2 impacts to ambient air from drill rig diesel engines permits costly mitigation methods to be avoided while still maintaining compliance with ambient air quality standards. Finally it should be noted that the “worst case” scenario shown for Table 3 is extreme in that it assumes that four engines will be operated on a given well pad simultaneously at 100% full load at 1200 rpm. In reality it is a very unlikely scenario that four engines would be operated at full load simultaneously.

Conclusions

While site-specific conditions characteristic of the Telephone Flat project were used to develop the data, the results and conclusions reached are generally applicable to geothermal well drilling and venting at any location. The key finding of the analyses is that significant cost savings and compliance with air quality standards can both be achieved by: 1.Customized design of well silencers and drill rig engine exhaust systems, and, 2. An iterative meteorological monitoring / abatement procedure. In addition, it was concluded that project-specific information in regards to calculating ambient NO_2 levels is needed for an accurate prediction of impacts and that NO_2 impacts can be over predicted without this project-specific information.

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Table 1
Comparison of Maximum One-hour Average H_2S Impacts from Thirty-foot and Sixty-foot Well Silencers*

Well Number	Thirty-foot Silencer		Sixty-foot Silencer	
	Max. 1-hr Impact ($\mu g/m^3$)	% of Hours above Standard	Max. 1-hr Impact ($\mu g/m^3$)	% of Hours above Standard
1	26.5	0	19.6	0
2	25.9	0	19.4	0
3	32.8	0	24.7	0
4	56.0	0.17	42.4	0.02
5	70.8	0.39	53.8	0.19
6	87.0	0.19	66.5	0.15
7	103.3	0.60	79.1	0.45
8	241.9	0.82	180.7	0.59
9	186.4	0.39	143.6	0.36
10	162.6	1.14	125.3	0.90
11	130.5	6.03	95.1	2.79
12	152.2	16.26	109.8	13.79
13	133.8	13.44	102.6	7.26
14	165.2	14.92	119.4	13.02

*Results in table are based on 12 foot diameter silencers, wells venting at 100% full production (367, 000 lbs /hr mass flow), 200° F exit temperature, 6.8 lbs H_2S/hr emission rate, and a gas (steam plus noncondensible gas) exit velocity of 9.5 ft/sec.

Table 2
Seasonal Variation of H_2S Impacts from Well Venting*

Well Number	Number of hours standard exceeded						
	April	May	June	July	August	Sept.	Oct.-March
1	Standard not exceeded						
2	Standard not exceeded						
3	Standard not exceeded						
4	0	1	0	0	0	0	1
5	0	0	1	0	0	1	21
6	0	4	0	0	0	0	14
7	1	5	0	4	1	3	41
8	1	8	0	2	0	4	56
9	1	8	2	2	0	1	30
10	1	3	2	1	1	1	100
11	Exceedences throughout year						
12	Exceedences throughout year						
13	Exceedences throughout year						
14	Exceedences throughout year						

* Data are for the 60 foot silencer and 100% full production scenario.

Table 3

Comparisons of Maximum One-hour NO_2 Impacts from Different Exhaust Systems and for Atmospheric NO to NO_2 Conversion Calculated by Different Methods for the "Worst-Case" Well Pad*

NO to NO_2 conversion method	13.5 ft, engines exhausted separately, horz. discharge (μg/m^3)	13.5 ft, engines exhausted together, vertical discharge (μg/m^3)	30 ft, engines exhausted together, vertical discharge (μg/m^3)	60 ft, engines exhausted together, vertical discharge (μg/m^3)
All NO converted to NO_2	14,240	4523	3395	2416
Ozone limiting	1557	586	473	375
Ozone limiting with kinetics	1490	519	406	308
Distance from well pad center (x,y) in meters	-50,100	50,0	150,200	150,200

*The results in table are based on 3 foot diameter stack, all four engines operating simultaneously at 100% full load and 1200 rpm, and 10% of the total primary NO_x emissions (before atmospheric oxidation) in the form of NO_2. The "worst-case" well pad corresponds to well pad number 8, as shown in Tables 1 and 2, which has a large topographic rise adjacent to it.