A Modeling Methodology to Estimate the Potential for Ground-Level Fogging from Wet-Scrubbed Plumes

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ABSTRACT

New federal and state requirements for major SO_2 emission reductions such as the CAIR program have resulted in an increase in the use of wet Flue Gas Desulfurization (FGD) systems particularly for electric generating units. Installation of a wet FGD system results in a substantial increase in the emissions of water vapor and liquid water. This increases the potential for plume-induced ground-level fogging in the vicinity of these plants.

A modeling methodology was developed to estimate the potential for the occurrence of ground-level fogging due to this increased water vapor and liquid water emissions from wet-scrubbed plumes. This methodology can be applied to assist a source in the determination of a stack height that will minimize the fogging impacts of wet-scrubbed plumes.

The methodology consists of:

1. Air dispersion modeling of the water vapor and liquid water emissions from the source
2. Post-processing of model-predicted ground-level water vapor concentrations to determine the probability of fogging and/or icing occurrence.

This paper discusses this methodology and provides examples of its application. It is directed to those government and private sector officials as well as those environmental groups and the general public concerned with the impact of new FGD systems on plume fogging in the surrounding area.

INTRODUCTION

Large numbers of electric power plants will install Flue Gas Desulfurization (FGD) systems to comply with the Clean Air Interstate Rule, the Clean Air Mercury Rule, the Clean Air Visibility Rule, and Consent Orders to address alleged deviations from U.S. EPA's New Source Review regulations.

These electric power plants will also install FGD systems to comply with new proposed and adopted state laws and regulations for statewide reductions of electric power plant air pollution emissions in such states as New York, North Carolina, Maryland and Illinois. FGD systems will also be installed by electric power plants to comply with the State Implementation Plans being revised to demonstrate attainment of the existing and new National Ambient Air Quality Standards for fine particulate matter (PM2.5) and ozone.

Finally, additional FGD systems will be installed due to the construction of new coal-fired electric power plants in response to growing electric energy needs and declining reserve margins.

Each FGD system will increase the emissions of water vapor and liquid water from its exhaust stacks. This raises the potential for plume-induced ground-level fogging/icing in the vicinity of the plant. Such fogging and icing may cause considerable local community complaints requiring potentially costly changes to the FGD subsystem and plant operating practices

There are no existing U.S. EPA approved air quality models for fogging and icing. The Electric Power Research Institute sponsored development of a model in the 1980's to predict visible plumes, drift, fogging, icing and shadowing from multiple cooling towers located at power plants. This model, known as SACTI, was developed and validated by Argonne National Laboratory.[1]

There are several problems with using this model to determine the occurrence and magnitude of fogging and icing from power plant exhaust stacks with FGD systems.

First, SACTI does not take advantage of the improvements in model predictions of plume centerline behavior and dispersion about the centerline resulting from research conducted over the past 20 years. The cumulative developments over this period led to the development of U.S. EPA's AERMOD Model that became the U.S. EPA recommended model for stationary sources in flat, rolling or complex terrain.[2,3]

Second, SACTI was validated using cooling tower plume observations instead of the stack plume observations used in validating AERMOD.

Third, SACTI does not address plume downwash due to building structures and a simplistic procedure for addressing plume interaction with surrounding terrain.

The purpose of this paper is to present a way to evaluate the potential for fogging and icing from power plant exhaust stacks with FGD systems using the latest research on plume centerline behavior and dispersion in a dispersion environment that includes downwash and complex terrain.

PROCEDURES AND DATA

The basic approach we developed for evaluating the potential for fogging and icing from power plant exhaust stacks with FGD systems consists of:

1. Applying the U.S. EPA Guideline Model, AERMOD [2], to predict ground-level concentrations of water vapor from the power plant FGD system.

2. Predicting whether ground level fogging/icing occurs using basic principles of condensation formation.

The hypothetical power plant we developed and applied this procedure to had the following characteristics. It is a coal-fired power plant of approximately 2,000 MW in a river valley with complex terrain. It has an 850 foot Good Engineering Practice (GEP) stack determined based on a physical modeling study that conformed with U.S. EPA guidance for conducting such studies to make GEP stack height determinations. This plant is located in a river valley with several nearby communities.

The plant was assumed to emit 12.9% water vapor by volume in the stack exhaust resulting in 252,062 grams/second of water vapor at 100% operating load. The plant was also assumed to release 378 grams/second of liquid water carryover from the mist eliminators. These are all typical operating characteristics for a large coal-fired power plant with an FGD system.

Since the liquid water carryover from the mist eliminators represents an insignificantly small fraction of the potential for water vapor condensation from the stack, the liquid water carryover from the mist eliminators was excluded from further consideration.

We assembled five years of hourly meteorological data from the closest National Weather Service Station with similarly complex terrain. We processed the meteorological data with U.S. EPA's meteorological preprocessor for the AERMOD Model, AERMET[3].

The land use type within three kilometers of the National Weather Service Station was determined. We chose the AERMOD default mode input parameters by land use type and season of year for albedo, Bowen Ratio and surface roughness. Next, we calculated the land-use weighted average values of default input parameters by season and direction from NWS station.

We selected 900 receptors in three nested grids about the plant. We applied the AERMAP terrain processor and digital elevation data files to determine the ground elevation of each receptor.

Next we applied the AERMOD Model to predict water vapor concentrations for each hour of five years at 900 receptors for a total of 900 x 5 x 8760=39,420,000 hourly predictions.

Using relationships on concentrations as a function of averaging time and the ratio of observed concentrations with and without terrain-effect downwash from a physical modeling study conducted at this plant, we developed a relationship of peak 10-minute concentrations to the predicted peak hourly concentrations from the AERMOD Model. This relationship was that each predicted hourly concentration was multiplied by 2.76 to predict the maximum 10-minute water vapor concentration each hour.

We next calculated the plume water vapor mixing ratio, the ambient mixing ratio and the total mixing ratio at each receptor for each hour using the highest 10-minute predicted water vapor concentration from the plume. This total mixing ratio for the peak 10-minute period within each hour was then compared to the Saturation Mixing Ratio at which condensation occurs to quantify the frequency and location of fogging due to the plume.

RESULTS

There were no 10-minute periods out of the 39,420,000 hourly predictions when the plume water vapor combined with the ambient moisture caused ground-level condensation/fogging.

Table 1 shows the predicted plume water vapor mixing ratios and meteorological conditions associated with the ten highest predicted ground-level water vapor concentrations in each meteorological year. The highest predicted plume water vapor mixing ratios at ground-level are on the order 6×10^{-5} to 9×10^{-5}, which is very low compared to typical ambient water vapor mixing ratios of 1 – 2%. Table 1 also indicates that the highest predicted plume water vapor mixing ratios predominantly occur during the summer months in the afternoon, under relatively warm temperatures (80+ degrees F) with dry relative humidities (i.e., 20 – 40%), and during cross-valley plume transport (i.e., wind directions from the NE-E). Under these conditions, the addition of plume moisture is not nearly sufficient to raise the ambient mixing ratio to the saturation point.

CONCLUSIONS

We developed a way to evaluate the potential for plume fogging that is generally applicable to wet scrubbed electric power plants. We applied this procedure to a hypothetical large coal-fired power plant in complex terrain using an FGD system with 12.9% water vapor emissions by volume and a GEP stack. Prediction results indicated that this plant did not produce incidents of ground level fogging. Therefore, no further increase in stack height is needed to reduce or eliminate the potential for plume fogging.

Since we did not use any flag pole receptors, the results of this study do not provide additional information on whether there might be a visible plume. Wide variations in relative humidity are common especially in areas of complex terrain. Such terrain effects may lead to more hours per year of atmospheric saturation or near-saturation than would normally occur with flat terrain raising the potential for plume-induced fogging episodes. There is considerable benefit to collecting and using site-specific meteorological data in evaluating the potential for plume fogging especially for plants located in complex terrain.

REFERENCES

1. Electric Power Research Institute, User's Manual: Cooling-Tower-Plume Prediction Code for the Seasonal and Annual Cooling Tower Impacts (SACTI) Model, Palo Alto, CA 1984

2. U.S. EPA, User's Guide for the AMS/EPA Regulatory Model – AERMOD, EPA-454/B-03-001, 2004, Research Triangle Park, NJ 27711

3. U.S. EPA, User's Guide for the AERMOD Meteorological Preprocessor (AERMET). EPA-454/B-03-002, 2004, Research Triangle Park, NC 27711.

Table 1: Prediction Results

Rank	AERMOD Conc.	Yr	Month	Day	Hr	Wind Direction	Wind Speed,m/s	Dry Bulb Temp, K	Relative Humidity	Station Pr, mb	Sat. Vapor Pr	Sat. Mixing Ratio	Conc. rs	rambient	Conc.	rplume	rtotal
1	26,991.86	86	7	22	16	40	2.6	301.45	40	978	38.84	0.0257	0.0256	0.0102	74,497.53	6.59E-05	0.0103
2	26,332.38	86	7	23	13	60	4.1	301.45	46	980	38.84	0.0257	0.0255	0.0117	72,677.37	6.42E-05	0.0118
3	26,332.38	86	7	23	13	60	4.1	301.45	46	980	38.84	0.0257	0.0255	0.0117	72,677.37	6.42E-05	0.0118
4	25,649.31	86	7	22	15	20	3.1	300.95	41	978	37.72	0.0250	0.0248	0.0102	70,792.10	6.25E-05	0.0102
5	25,369.91	86	7	22	17	20	5.7	301.45	38	978	38.84	0.0257	0.0256	0.0097	70,020.95	6.20E-05	0.0098
6	25,267.50	86	5	26	14	90	6.7	300.35	32	974	36.42	0.0242	0.0240	0.0077	69,738.31	6.17E-05	0.0078
7	25,267.50	86	5	26	14	90	6.7	300.35	32	974	36.42	0.0242	0.0240	0.0077	69,738.31	6.17E-05	0.0078
8	25,267.50	86	5	26	14	90	6.7	300.35	32	974	36.42	0.0242	0.0240	0.0077	69,738.31	6.17E-05	0.0078
9	24,986.04	86	6	21	15	100	2.1	299.85	35	978	35.37	0.0233	0.0232	0.0081	68,961.48	6.07E-05	0.0082
10	24,932.49	86	7	23	16	30	3.1	302.55	43	978	41.39	0.0275	0.0273	0.0118	68,813.68	6.11E-05	0.0118
1	28,619.07	87	6	17	14	30	2.6	301.45	37	975	38.84	0.0258	0.0257	0.0095	78,988.64	7.01E-05	0.0096
2	28,619.07	87	6	17	14	30	2.6	301.45	37	975	38.84	0.0258	0.0257	0.0095	78,988.64	7.01E-05	0.0096
3	27,619.58	87	6	24	15	40	3.1	302.05	40	972	40.21	0.0268	0.0267	0.0107	76,230.05	6.80E-05	0.0108
4	27,588.17	87	7	23	14	260	2.1	306.45	40	976	51.64	0.0348	0.0346	0.0138	76,143.36	6.86E-05	0.0139
5	27,588.17	87	7	23	14	260	2.1	306.45	40	976	51.64	0.0348	0.0346	0.0138	76,143.36	6.86E-05	0.0139
6	27,364.04	87	7	31	15	20	2.6	304.25	36	973	45.62	0.0306	0.0304	0.0110	75,524.76	6.78E-05	0.0110
7	27,301.36	87	7	31	13	60	2.6	303.75	38	973	44.34	0.0297	0.0295	0.0112	75,351.75	6.75E-05	0.0113
8	27,301.36	87	7	31	13	60	2.6	303.75	38	973	44.34	0.0297	0.0295	0.0112	75,351.75	6.75E-05	0.0113
9	27,089.77	87	6	24	14	70	4.1	301.45	43	972	38.84	0.0259	0.0258	0.0111	74,767.77	6.66E-05	0.0111
10	26,908.90	87	7	23	16	260	2.6	307.05	37	975	53.40	0.0360	0.0359	0.0133	74,268.55	6.71E-05	0.0133

Notes:

r_a is the ambient water vapor mixing ratio

r_{plume} is the plume water vapor mixing ratio

r_{total} is the total water vapor mixing ratio

P_r is pressure in millibars

Conc. is concentration of water vapor in ug/m3.

Conc. rs is the water vapor concentration at the Saturation Mixing Ratio

Table 1 (continued)

Rank	AERMOD Conc.	Yr	Month	Day	Hr	Wind Direction	Wind Speed,m/s	Dry Bulb Temp, K	Relative Humidity	Station Pr, mb	Sat. Vapor Pr	Sat. Mixing Ratio	Conc. rs	rambient	Conc.	rplume	rtotal
1	30,639.16	89	7	24	12	20	1.5	306.45	41	982	51.64	0.0345	0.0344	0.0141	84,564.09	7.58E-05	0.0142
2	30,537.45	89	7	23	16	90	2.1	307.05	40	981	53.40	0.0358	0.0356	0.0143	84,283.35	7.57E-05	0.0143
3	30,537.45	89	7	23	16	90	2.1	307.05	40	981	53.40	0.0358	0.0356	0.0143	84,283.35	7.57E-05	0.0143
4	30,537.45	89	7	23	16	90	2.1	307.05	40	981	53.40	0.0358	0.0356	0.0143	84,283.35	7.57E-05	0.0143
5	29,813.35	89	7	25	15	20	2.6	307.05	41	980	53.40	0.0358	0.0357	0.0146	82,284.84	7.40E-05	0.0147
6	29,497.57	89	7	24	14	110	2.6	305.35	42	982	48.55	0.0324	0.0322	0.0135	81,413.29	7.27E-05	0.0136
7	29,389.35	89	2	18	12	360	1.5	271.45	51	988	5.45	0.0035	0.0034	0.0018	81,114.62	6.40E-05	0.0018
8	29,389.35	89	2	18	12	360	1.5	271.45	51	988	5.45	0.0035	0.0034	0.0018	81,114.62	6.40E-05	0.0018
9	29,223.86	89	2	18	12	360	1.5	271.45	51	988	5.45	0.0035	0.0034	0.0018	80,657.86	6.36E-05	0.0018
10	29,058.26	89	7	24	13	10	1.5	307.05	40	982	53.40	0.0358	0.0356	0.0142	80,200.80	7.20E-05	0.0143
1	28,686.62	90	8	28	23	60	9.3	299.25	72	969	34.14	0.0227	0.0226	0.0163	79,175.06	7.02E-05	0.0163
2	28,686.62	90	8	28	23	60	9.3	299.25	72	969	34.14	0.0227	0.0226	0.0163	79,175.06	7.02E-05	0.0163
3	28,598.72	90	7	27	12	30	2.1	302.05	49	981	40.21	0.0266	0.0265	0.0130	78,932.48	6.98E-05	0.0130
4	28,598.72	90	7	27	12	30	2.1	302.05	49	981	40.21	0.0266	0.0265	0.0130	78,932.48	6.98E-05	0.0130
5	28,175.07	90	11	19	12	300	1.5	280.35	46	976	10.26	0.0066	0.0066	0.0030	77,763.20	6.41E-05	0.0031
6	28,021.45	90	8	9	15	60	4.1	300.95	57	977	37.72	0.0250	0.0249	0.0142	77,339.21	6.84E-05	0.0142
7	28,021.45	90	8	9	15	60	4.1	300.95	57	977	37.72	0.0250	0.0249	0.0142	77,339.21	6.84E-05	0.0142
8	27,945.62	90	6	16	16	90	2.6	304.25	52	973	45.62	0.0306	0.0304	0.0158	77,129.91	6.92E-05	0.0159
9	27,945.62	90	6	16	16	90	2.6	304.25	52	973	45.62	0.0306	0.0304	0.0158	77,129.91	6.92E-05	0.0159
10	27,945.62	90	6	16	16	90	2.6	304.25	52	973	45.62	0.0306	0.0304	0.0158	77,129.91	6.92E-05	0.0159

Notes:

r_a is the ambient water vapor mixing ratio

r_{plume} is the plume water vapor mixing ratio

r_{total} is the total water vapor mixing ratio

P_r is pressure in millibars

Conc. is concentration of water vapor in ug/m3.

Conc. rs is the water vapor concentration at the Saturation Mixing Ratio