

# **Ways to Estimate the Potential for Plume Fogging from Wet Scrubbed Electric Power Plants**

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# Purpose of Study

Large numbers of electric power plants will install Flue Gas Desulfurization (FGD) systems to comply with:

- Consent Orders
- CAIR
- CAMR
- Future ozone and PM<sub>2.5</sub> SIP requirements

## Purpose of Study

- Each FGD system will increase the emissions of water vapor and liquid water from its exhaust stack.
- This raises the potential for plume-induced ground-level fogging/icing in the vicinity of the plant.

## Purpose of Study

- Such fogging and icing may cause considerable local community complaints requiring potentially costly changes to the FGD subsystem and plant operating practices

## Purpose of Study

- There are no existing U.S. EPA-approved air quality models for fogging and icing

# Purpose of Study

- **Develop way to evaluate the potential for fogging and icing from power plant exhaust stacks with FGD systems**

# OVERVIEW OF APPROACH

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

# OVERVIEW OF APPROACH

2. We predicted whether ground level fogging/icing occurred using basic principles of condensation formation



# PLANT/FGD SYSTEM PROFILE

1. Coal-fired power plant exceeding 1500 MW in river valley with complex terrain
2. 850 foot GEP Stack based on physical modeling study
3. Several nearby communities mainly in river valley

# DATA INPUT

1. **Develop the water vapor emissions inventory:**
  - 12.9% water vapor by volume in the stack exhaust
  - 252,062 grams/second water vapor at 100% operating load

# DATA INPUT

2. **Develop the water droplet emissions inventory**
  - The liquid water carryover from the mist eliminators is estimated at 378 grams/second.
  - Conclusion: Water droplet emissions are insignificant compared to emissions of water vapor. Exclude from further analysis.

# DATA INPUT

## 3. Assemble Meteorological Data

- 5 years hourly surface and upper air data from closest National Weather Service station

**Note:** on-site data always preferred if available

# DATA INPUT

## 3. Assemble Meteorological Data

- AERMET meteorological pre-processor used to process the data required for AERMOD.

# DATA INPUT

## 4. Determine Land Use within 3 Km of the National Weather Service Station

Land Use Type	Fractional Land Use	
	Sector 1 (15° – 270°)	Sector 2 (270° – 15°)
Urban	0.75	0.10
Deciduous	0.20	0.85
Grassland	0.05	0.05
<b>Total % Land Use</b>	<b>1.00</b>	<b>1.00</b>

# DATA INPUT

## **5. Select AERMOD default mode input parameters by land use type and season of year:**

- Albedo
- Bowen Ratio
- Surface Roughness

Source: AERMET User's Guide

# DATA INPUT

- 6. Calculate the land-use weighted average values of default input parameters by season and direction from plant**



### Sector 1 (15°-270°)

Albedo				
	Winter	Spring	Summer	Autumn
Urban	0.2625	0.105	0.12	0.135
Deciduous	0.1	0.024	0.024	0.024
Grassland	0.03	0.009	0.009	0.01
<b>Total</b>	<b>0.393</b>	<b>0.138</b>	<b>0.153</b>	<b>0.169</b>
Bowen Ratio - Wet Conditions				
	Winter	Spring	Summer	Autumn
Urban	0.375	0.375	0.75	0.75
Deciduous	0.1	0.06	0.04	0.08
Grassland	0.025	0.015	0.02	0.025
<b>Total</b>	<b>0.500</b>	<b>0.450</b>	<b>0.810</b>	<b>0.855</b>
Surface Roughness				
	Winter	Spring	Summer	Autumn
Urban	0.75	0.75	0.75	0.75
Deciduous	0.1	0.2	0.26	0.16
Grassland	0.00005	0.0025	0.005	0.0005
<b>Total</b>	<b>0.850</b>	<b>0.953</b>	<b>1.015</b>	<b>0.911</b>

# DATA INPUT

## 7. Select Receptors:

<b>RECEPTOR GRID CENTERED AT PLANT</b>			
<b>Grid</b>	<b>Size</b>	<b>Receptor Spacing</b>	<b>Number Receptors</b>
Inner	1x1 km	100 meters	100
Middle	5x5 km	250 meters	400
Outer	10x10 km	500 meters	400
<b>TOTAL</b>			<b>900</b>

# DATA INPUT

## 8. Determine receptor elevations

- AERMAP terrain processor
- Digital elevation data files

# MODELING Task 1

- Apply AERMOD to predict water vapor concentrations for each hour of 5 years at 900 receptors

**$900 \times 5 \times 8760 = 39,420,000$  predictions**

# MODELING Task 1

- **Problem 1:** AERMOD Model does not address terrain-induced downwash yet highest upwind terrain exceeds stack height

# MODELING Task 1

- **Solution:** Physical modeling study of plant showed the highest 10-minute “measured” concentration using the actual complex terrain was **1.93 times** the highest 10-minute measured concentration with flat terrain

# MODELING Task 1

- **Problem 2:** AERMOD Model does not predict the maximum 10-minute concentration within each hour although 10 minutes of fogging could trigger community complaints

# MODELING Task 1

Observations of maximum plume centerline concentrations and averaging times show the maximum concentration per period varies inversely with averaging time raised to between the 0.17 and 0.2 power

Source: Turner, D.B., Workbook of Atmospheric Dispersion Estimates, U.S. EPA, Research Triangle Park, NC, 1970.



# MODELING Task 1

## Solution:

$$C_{\max 10} = C_{60} * (60/10)^{0.2}$$

The highest 10-minute concentration each hour equals  $(60/10)^{0.2} = \mathbf{1.43}$  times the predicted hourly average concentration

# MODELING Task 1

**Combining the two solutions**, each predicted hourly concentration was multiplied by 1.93 times 1.43 = **2.76** to predict the maximum 10-minute concentration each hour

## MODELING Task 2

Calculate the plume water vapor mixing ratio from the predicted 10-minute plume water vapor concentration  $C_{\max 10}$  (ug/m<sup>3</sup>) :

$R_{\text{plume}}$  = grams plume water vapor/grams air

$$= C_{\max 10} (2.8706 \times 10^{-9} T) / P$$

# MODELING Task 3

**Calculate the ambient water vapor mixing ratio**

$R_{\text{ambient}} = \text{grams ambient water vapor/grams air}$

$= R_s \times \text{Relative Humidity}$

where  $R_s$  is the Saturation Mixing Ratio

# MODELING Task 3

**Calculate the ambient water vapor mixing ratio**

$$\mathbf{R_s} = (0.622)e_s / (\mathbf{P} - e_s) \times \text{Relative Humidity}$$

where  $e_s$  is saturation vapor pressure and  $\mathbf{P}$  is atmospheric pressure in millibars

# MODELING Task 4

**Calculate the Total Mixing Ratio:**

$$R_{\text{total}} = R_{\text{plume}} + R_{\text{ambient}}$$

# MODELING Task 5

Compare the Total Mixing Ratio ( $R_{\text{total}}$ ) to the Saturation Mixing Ratio ( $R_s$ ):

**If  $R_{\text{total}} \geq 0.995 R_s$  ,  
ground-level fogging is assumed to occur**

# MODELING RESULTS

- There were **no 10-minute periods** when the plume water vapor combined **with** the ambient moisture caused ground-level **condensation/fogging**



# MODELING RESULTS

- The highest plume water vapor mixing ratios predominantly occur during **summer afternoons**, under relatively **warm temperatures** (80+ degrees F) and **dry relative humidities** (20-40%)

# MODELING RESULTS

- 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**

# CONCLUSIONS

We applied this procedure to a large coal-fired power plant in complex terrain using an FGD system with 12.9% water vapor emissions by volume and a GEP stack.

# CONCLUSIONS

Prediction results indicated that this plant **did not** produce incidents of ground level fogging

# CONCLUSIONS

## Caution:

Wide variations in relative humidity are common especially in areas of complex terrain

# CONCLUSIONS

## **Caution:**

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**

# CONCLUSIONS

## **Caution:**

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