Estimates of Water Curtain Efficiency For Ammonia

Introduction

The most recent version of the CHARM® software has been extended to allow multiple releases; multiple species; particle formation, coagulation, evaporation/condensation, deposition, and interaction with gases; and chemical reactions. To test the usefulness of the latest version it has been used in a number of cases where standard air dispersion models are not normally used. One of those cases is in estimating the efficiency of a water curtain in reducing the concentration impacts from a release of ammonia.

Scenario

The case modeled is one of a ground release of ammonia vapor with a source of water droplets higher than the release site and downwind. To test the effect of different flow rates a number of water emission rates are used. One simulation is performed with only the ammonia emission to determine the non-mitigated case.

Ammonia Release

A horizontal cylinder is assumed to contain ammonia. The cylinder is 10 feet long and is 10 feet in diameter. A one-inch hole is put into the container. The storage temperature of the container is ambient (78 °F) and the storage pressure is the equilibrium pressure for that temperature (calculated by CHARM as 137 psig). Any liquid release is forced to vaporize via a user input option.

Water Releases

The water release rates were varied for this analysis and are 5,000, 50,000, 132,000, and 264,000 lbs/hr. All releases were from a 30-foot by 30-foot source 60 feet downwind and 30 feet above the release site. The water is delivered by a spray mechanism that releases it with uniform coverage and negligible initial vertical speeds. The particle bin size distribution of the released water droplets is given in the table below.

Lower Bin Diameter (μm)	Number / cm^3
50	0
53.1329	0
56.4622	0
60	0
63.7595	0
67.7546	0
72	0
76.5114	0
81.3055	0
86.4	0
91.8137	0

97.5666	1
103.68	1
110.176	1
117.08	1
124.416	1
132.212	1
140.496	1
149.299	1
158.654	0
168.595	0
179.159	0
190.385	0
202.314	0
214.991	0
228.462	0
242.777	0
257.989	0
274.154	0

The Number/cm^3 in the table is used in a relative fashion for emissions. The distribution is normalized so that the mass fraction of the sum of all particles in the distribution is one. Then the total water mass emission rate is used to determine the rate of mass addition to each size bin. In this case the Number/cm^3 is a constant for all bins from about 100 to about 150 µm.

Chemistry

The user defines a chemical reaction that allows ammonia vapor to be absorbed by particles. The assumed reaction for this analysis is:

$$NH_3(g) + H_2O(l) \dashrightarrow NH_4^+ + OH^-$$

The reaction rate is given[1] as:

$$\text{Reaction Rate} = 4\,\pi\,D\,r$$

Where D = binary diffusion coefficient of ammonia in air;
r = radius of particle absorbing the ammonia.

Meteorology

[1] Twomey, S., 1977. Atmospheric Aerosols. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

The meteorology used is given in the table below. Two relative humidity values were used to illustrate the sensitivity of this parameter on the efficiency. The largest water release was simulated with both humidity values.

Relative Humidity:	50 and 95 %
Ambient Temperature:	78 °F
Ambient Pressure:	1 atms
Stability Class:	D
Wind measurement height	10 m
Wind Speed:	10 mph

<u>Grid</u>

The grid used for the calculation is flat with a surface roughness of 10 cm throughout. There are 11 grid cells in the crosswind direction and 40 grid cells in the along-wind direction. The horizontal dimensions of the grid cells are 10 feet by 10 feet. There are 12 grid cells in the vertical with 5 foot spacing.

Results

Each scenario was simulated until a steady-state condition was reached. The calculation grid for each simulation was output in text format. Then the crosswind and vertical cells were summed for each downwind cell spacing. These sums were used to determine the fraction of change that occurred from the base case of ammonia being released alone (no mitigation) for each scenario as a function of downwind distance. Some mass may have been lost through the top of the grid during calculation since the grid is only 60 feet in height.

The results of the efficiency calculations are given in the figure at the end of this document in Figure 1.

Conclusions

Results of the simulations support the following conclusions:

- Higher water rates lead to higher scavenging efficiencies.
- Higher relative humidity values do not lead to significant efficiency increases.
- At least for this case, 5,000 lbs/hr does not provide significant efficiencies.
- Plume dynamics changes for low water rates may lead to higher ground-level concentrations.
- Scavenging efficiencies of 40 to 60 percent may be possible.
- Other meteorology and site configurations may lead to different results.

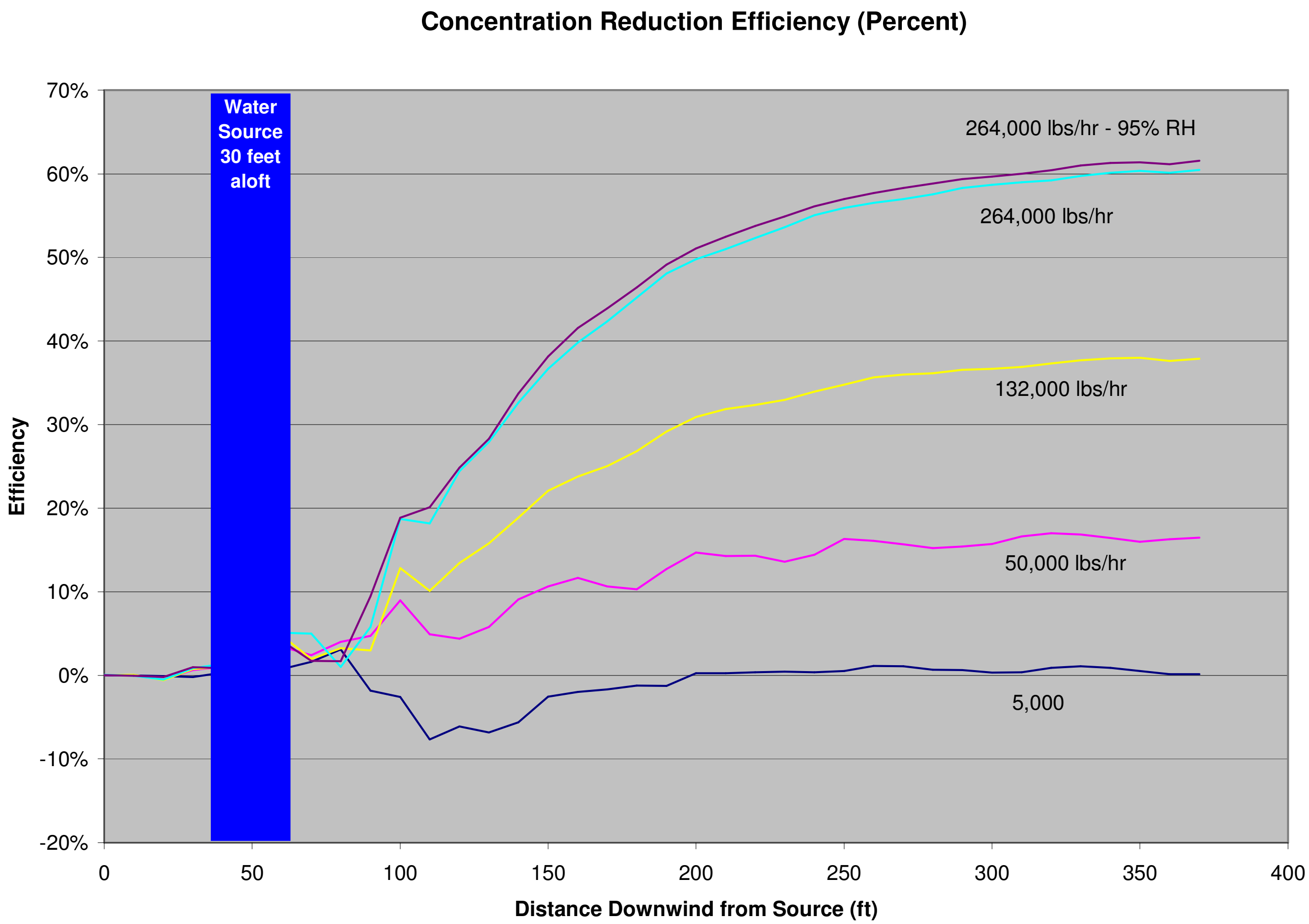

Figure 1. Ammonia Scavenging Efficiency at Ground Level as a Function of Downwind Distance.