Droplet Deposition Downwind Of A Cooling Tower

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 droplet deposition rate downwind of a cooling tower.

Scenario

Meroney[1] (2004) describes the results of simulating the deposition impacts from the Chalk Point Cooling Towers. Field data was available for the paper from a study in 1977. Case A in the paper was selected for simulation.

There are two natural-draft cooling towers at Chalk Point. Only one is assumed in the simulation. The tower is 400 feet high with a 90-foot diameter exit. A drift of water droplets with sodium in solution is emitted from the tower.

A sodium emission rate of 1.86 g/s is specified in the paper, as well as meteorological parameters. The exit temperature is given in the paper as 315.3 K. The vertical exit velocity of the release is given as 4.5 m/s. Two parameters are missing in the paper: water droplet emission rate and stability class.

For the emission rate, other information was found on the Internet for the Chalk Point Power Plant. That information indicated a drift loss of 0.002 percent of total flow (also stated in the Meroney paper), a Makeup flow of 2.5 percent of total flow, and an actual Makeup flow of 250,000 gallons per minute. A drift emission rate of water of 200 gallons per minute (12.62 kg per second) was calculated.

Based on a description of the time of day (evening) and wind speeds, a stability class of D was selected.

The water droplets containing sodium are modeled as pure water. Since CHARM has the capability, the simulations are performed with and without evaporation. The Meroney paper did not include evaporation because the relative humidity is so large (93%).

<u>Particle Sizes</u>

As described in Meroney, the water particles are assumed to follow a Rosin-Rammler particle distribution, which is in the form of:

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[1] Robert N. Meroney, (October 25, 2004), "CFD Prediction of Cooling Tower Drift" http://www.engr.colostate.edu/~meroney/projects/CFD_Prediction_of_Cooling_Tower_Drift.pdf

$$F_c = \exp\left(-\left(\frac{d}{d_{mean}}\right)^n\right)$$

where F_c = cumulative mass fraction up to diameter d;
d_{mean} = mean particle diameter; and
n = shape factor.

For Case A in the Meroney paper, the value of d_{mean} is 0.09 mm and the value of n is 0.65.

CHARM can use cumulative mass fraction to determine the number density of particles as a function of particle size. The CHARM determined particle bin size distribution of the released water droplets is given in the table below.

Lower Bin Diameter (μm)	Number / cm^3
1	1.24359
1.25893	1.44368
1.58489	1.59862
1.99526	1.84788
2.51189	2.16036
3.16228	2.48561
3.98107	2.50575
5.01187	4.44127
6.30957	4.44127
7.94328	4.44127
10	4.44127
12.5893	4.44127
15.8489	4.44127
19.9526	4.44127
25.1189	4.44127
31.6228	4.44127
39.8107	4.42996
50.1187	3.34338
63.0957	3.34338
79.4328	3.34338
100	3.34338
125.893	3.34338
158.489	3.34338
199.526	3.34338
251.189	3.34338
316.228	3.34338
398.107	3.31181
501.187	0.277946
630.957	0.277946

794.328	0.277946

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.

Meteorology

The meteorology used for Case A is given in the table below

Relative Humidity:	93 %
Ambient Temperature:	295.3 K
Ambient Pressure:	1 atms
Stability Class:	D
Wind measurement height	50 m
Wind Speed:	5 m/s

Grid

The grid used for the calculation is flat except for the existence of the 124 m tall cooling tower itself. A surface roughness of 30 cm is assumed throughout. There are 15 grid cells in the crosswind direction and 25 grid cells in the along-wind direction. The horizontal dimensions of the grid cells are 50 m by 50 m. There are 15 grid cells in the vertical with 10 m spacing.

Results

The deposition rates as given in the Meroney paper are for an average value over an arc of about 30 degrees. The CHARM results at the centerline of the plume and 15 degrees either side were used to calculate an average throughout the arc. An example of the centerline deposition amount as a function of time for the non-evaporation case is given at the end of this document in Figure 1. The slope of the deposition amount line gives the deposition rate.

The results for the deposition rates (kg/month km^2) are given in the following table:

Distance downwind (m)	Observed	CHARM (No evaporation)	CHARM (Evaporation)	Meroney
500	1080	448	293	758
1,000	330	301	192	297

Conclusions

There appears to be less agreement between the CHARM results and measured data when taking evaporation into account then when comparing the CHARM results and measured data when evaporation is ignored. This could be due to an overestimation in the model, or the evaporation rate of water containing sodium may, in reality, be much lower than that for pure water.

At a minimum, CHARM appears capable of estimating deposition rates of the same order as measured.

There are a number of input modifications that could be done within the uncertainty of the release description to try to increase the agreement with the results. The cooling tower was modeled as a monolithic block. The grid in the model could be made to more closely resemble the cone shape of the cooling tower. This would affect the winds in the downwind area. The model is also capable of modeling non-integer stability classes. Changing the stability class by one half a class (e.g. D.5 or C.5) could effect the dispersion of the emission.

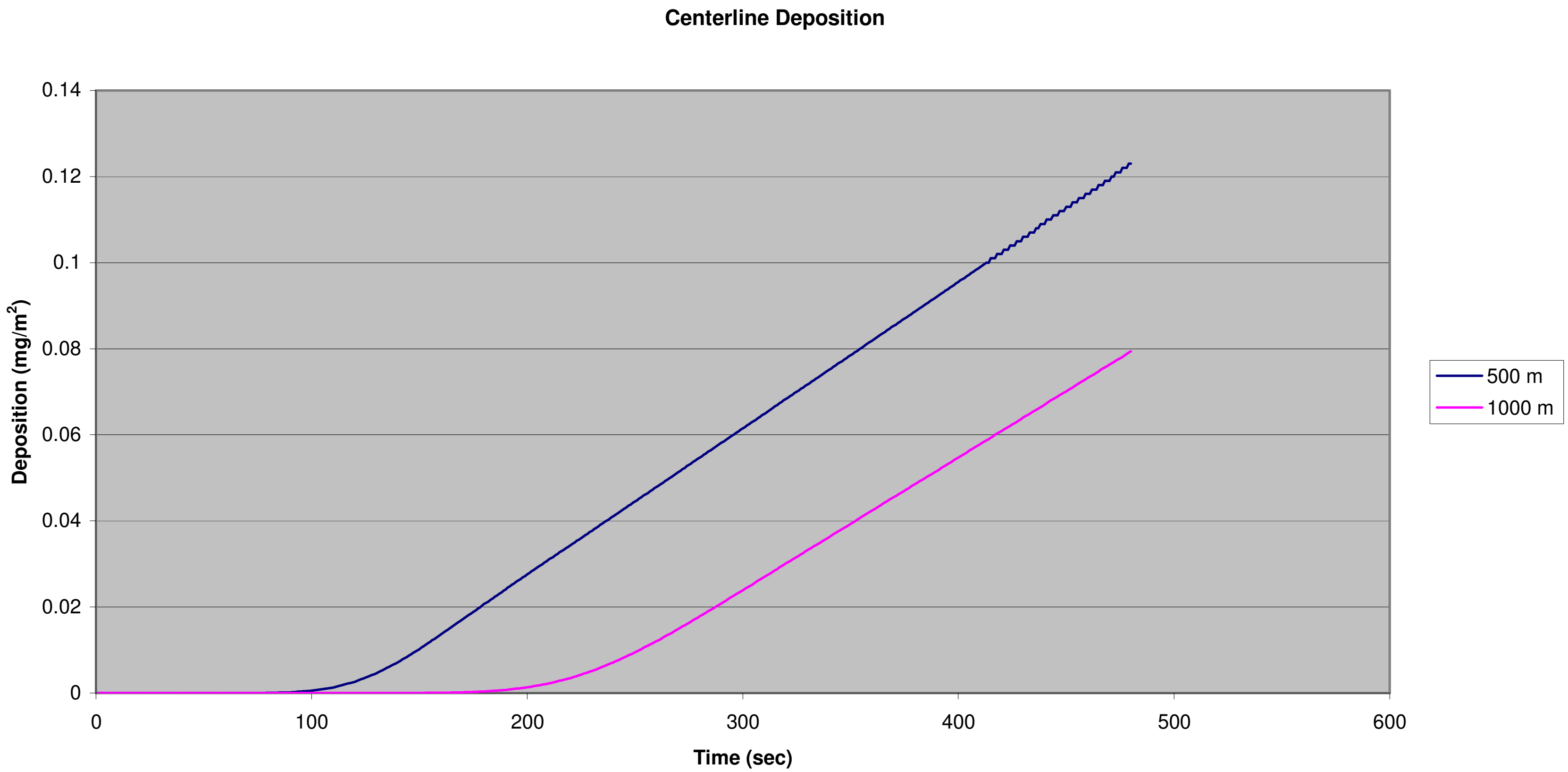

Figure 1. Deposition as a function of time for non-evaporating case.