CFD Prediction of Cooling Tower Drift in an Urban Environment

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ABSTRACT: A computational fluid dynamics (CFD) code including Lagrangian prediction of the gravity driven but stochastic trajectory descent of droplets is considered to predict plume rise, surface concentrations, and surface drift deposition. CFD drift deposition calculations are performed for a specific urban cooling tower situation with and without the urban buildings surrounding the cooling tower complex present to produce a set of multiplicative factors that could be used to correct seasonal or annual predictions for the presence of large urban structures.

KEYWORDS: Drift, Deposition, Cooling Tower, Urban Pollution.

1 INTRODUCTION

Drift of small water droplets from mechanical and natural draft cooling tower installations can contain water treatment chemicals such that contact with plants, building surfaces and human activity can be hazardous. Prediction of drift deposition is generally provided by analytic models such as the US Environmental Protection Agency approved ISCST3 (Industrial Source Complex Short Term Version 3) [1] or SACTI (Seasonal-Annual Cooling Tower Impact) [2] codes; however, these codes are less suitable when cooling towers are located midst taller structures and buildings. A computational fluid dynamics (CFD) code including Lagrangian prediction of the gravity driven but stochastic trajectory descent of droplets was previously considered and compared to data from the 1977 Chalk Point Dye Tracer Experiment [3]. Similar CFD techniques have been used successfully to predict rain fall deposition in valleys and on buildings [4, 5]. The CFD program predicted plume rise, surface concentrations, plume centerline concentrations and surface drift deposition for the Chalk Point study within the bounds of field experimental accuracy.

1.1 *Creation of a CFD Protocol to Correct Drift for Building Effects*

In order to evaluate the long-term health effects of droplet drift and deposition accumulation from a source such as a cooling tower, it is appropriate to accumulate information for seasonal and annual periods that include the actual distribution of wind orientations, wind speeds, and humidity and thermal conditions observed at the location. Unfortunately, the CFD method which includes building configurations and adjusts for enhanced turbulence and downwash in the building wakes is not conveniently applied to the superposition of such a wide range of situations due to time and economic constraints. On the other hand, analytic codes such as SACTI [2] which do permit seasonal and annual weighting of air pollution drift and deposition predictions do not incorporate the full effects of building wakes. Hence, a method was sought to adjust or calibrate drift code predictions for building effects using CFD results. This paper considers CFD calculations performed for a specific urban cooling tower situation with and without the urban buildings surrounding the cooling tower complex present to produce a set of multiplicative factors that could be used to correct conventional seasonal or annual drift model predictions for the presence of large urban structures. Similar factors have been proposed before to account for terrain effects on dispersion [6].

1.2 *Urban Complex Test Case*

It is anticipated that the presence of tall upwind buildings, terrain elevation changes and irregular arrangement of buildings in an urban area will accelerate droplet deposition downwind of a cooling tower facility. Downdrafts and turbulence associated with building wakes are known to accelerate the downward motion of drift particles. Several computational domains were created to study a set of actual mechanical draft cooling towers located surrounded by a downtown section of a major US city. The domain dimensions were typically 600 m long, 300 ft wide and 150 to 230 m deep with a mixture of from 1.5 to 2.5 million hexagonal and tetrahedral cells. Building heights within the domain ranged from 3 to 175 m tall with footprints ranging from 6 to 23,000 sq m. The cooling tower facility consisted of 11 units in a U-shaped tower/turbine building complex which emitted plumes from stacks 12 m above grade.

2 COMPUTATIONAL FLUID MODELING

The commercial software selected for these calculations solves the three-dimensional Reynolds averaged equations of motion discretized using a control volume approach for flow, pressure, turbulence, and concentration distributions [7]. The Reynolds stress terms are modeled by one of several turbulence models. Since in this study the behavior of cooling tower drift is emphasized and not flow in bluff-body separation and recirculation zones, the standard κ-ε turbulence model with standard wall functions was considered adequate. Also recent CFD calculations of dispersion in urban areas have satisfactorily used the standard κ-ε model [8]. The standard κ-ε turbulence model assumes isotropic turbulence at the sub-grid scale and uses transport equations for the turbulent kinetic energy (κ) and its dissipation rate (ε). Ground and wall surfaces were specified as rigid planes with a specified roughness. Inlet (upwind) velocity and turbulence profiles were selected to reproduce field observations.

2 DISCRETE PHASE MODELING

Once a total flow field is defined, the software may be configured to calculate the Lagrangian particle tracks of drift droplets emitted from the cooling tower exhaust nozzles. Particle sizes can be uniform or a specified particle distribution. Particle material can be inert or droplets that undergo evaporation and change in diameter over their lifetime. Particle trajectories can be calculated as simple ballistic trajectories uninfluenced by turbulence, or they can include stochastic dispersion due to the weighted effects of local turbulence and wind speed variations. For the Lagrangian stochastic approach droplets are released from the cooling-tower stack and their movement tracked based on the pre-calculated mean wind field and turbulence properties predicted by the RANS model. The particle positions are obtained by integrating the trajectory equations using the instantaneous fluid velocities ($U_i + u'_i$) along the particle path, where U_i are the mean velocity components and u'_i are the velocity fluctuations related to the local turbulence intensity through a normally distributed random number, which is constant for each "eddy lifetime". Alternatively, the software can be configured to simultaneously calculate fluid motions and particle behavior. This option permits the inclusion of phase change effects on plume rise and droplet size as the particles evaporate or condense during travel; however, inclusion of this option can significantly increase computational time since the calculation requires a full transient solution.

3 ZONAL CALCULATION OF DEPOSITION RATES

The program also has an option to track total mass accumulation rates on designated surfaces (or zones) as well as perform total mass balances on the particles released from the source locations. Thus, it was decided to divide the downwind ground and building regions into discrete swaths or zones 76 m wide perpendicular to each wind orientation extending from the downwind edge of the cooling tower facility out to 381 m. This distance extends beyond the limits of the primary deposition region. Deposition rates in units of kg/sec were predicted for the zone upwind of the cooling tower facility, on the cooling tower complex, and on five ground and building zones. The remaining particles escaped out the end of the computational domain. Figures 1 and 2 display the ground and building zones for a wind orientation of 180^o for the isolated cooling tower facility and the fully configured building cases, respectively.

4 COMPUTATIONAL RESULTS AND DISCUSSION

Calculations were performed for four wind orientations (160^o, 180^o, 220^o, and 240^o), three wind speeds (2.5, 5.0, and 7.5 m/sec at a height of 52 m, power law coefficient equal to 0.25), and droplets were emitted vertically in a air/vapor plume at 8.5 m/sec from the cooling tower units 1 through 11 at a rate of 1 kg/sec and a Rosin-Rammler droplet distribution (characterized by a mean diameter of 0.1 mm, a minimum diameter of 0.01mm, a maximum diameter of 1 mm, and a shape factor, n, equal to 1.0). Mass deposition rates (kg/sec) were calculated for each zone for the four wind orientations, 160^o, 180^o, 220^o, and 240^o, respectively.

4.1 *Multiplication Factors*

The ratio of the mass accumulation rate for a given zone and a fully configured building case to the mass accumulation for the equivalent zone and the isolated cooling tower facility case is designated here as a deposition Multiplication Factor (MF). If one then takes the average of the five zonal deposition Multiplication Factors one obtains the Average Multiplication Factor (AMF) for a given wind orientation. Thus, the final product of the additional calculations is a set of four AMF values to be interpolated among wind sectors used during ISC or SACTI annual calculations. Tables 1 and 2 display the MF and AMF values for the four wind orientations, 160^o, 180^o, 220^o, and 240^o, respectively. Figures 3 to 4 display similar information in the form of bar charts.

4.2 *Conclusions*

A typical set of coefficients have been provided that might be used to adjust the results of seasonal or annual deposition predictions using analytic programs such as ISC Prime or SATCI. The multiplicative and average multiplicative factors produced (MF and AMF) are based on reasonable scientific certainty concerning the physics of the fluid processes and the analytic and computational methods employed.

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Distance (ft)	MF 160 deg	MF 180 deg	MF 220 deg	MF 240 deg
0-250	9.06	1.951	0.79	1.58
250-500	4.87	1.75	1.96	3.18
500-750	2.42	1.10	1.65	2.80
750-1000	1.45	1.21	0.66	1.76
1000-1250	no data	1.25	1.26	0.51
Average	4.45	1.45	1.27	1.97
Total trapped	5.87	2.16	1.44	1.75
Trapped ground	4.35	1.54	1.17	1.93

Table 1 Multiplication Factors (MF)

Velocities	AMF 160 deg	AMF 180 deg	AMF 220 deg	AMF 240 deg
U = 2.5mps	5.60			2.03
U = 5.0mps	4.45	1.45	1.27	1.97
U = 7.5mps	4.40			1.09
Average	4.82	1.45	1.27	1.69

Table 2 Average Multiplication Factors (AMF)

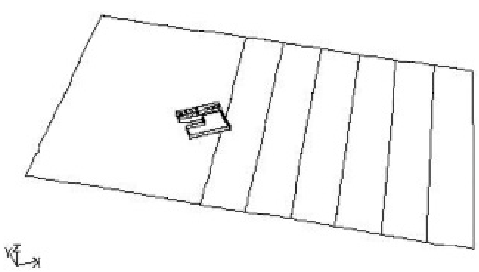

Figure 1 Isolated CT including 75 m wide zones, 180°

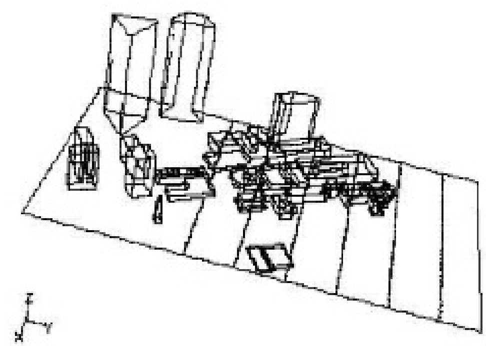

Figure 2 CT in urban area with 75 m wide zones, 180°

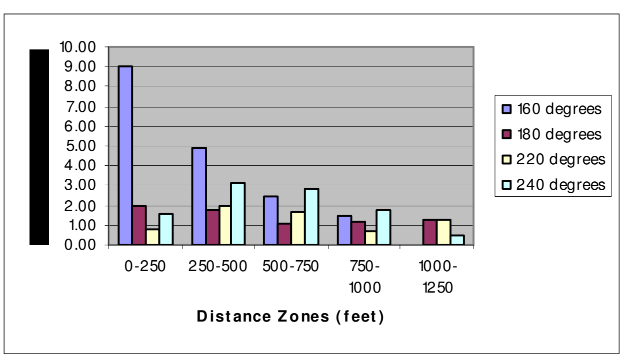

Figure 3 Zonal MF 160-240 deg, U = 5 mps

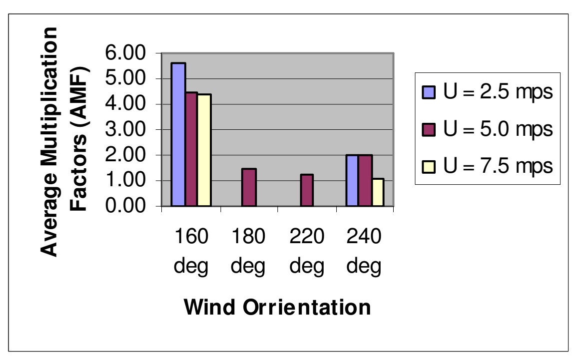

Figure 4 Zonal AMF, 160-240 deg, U = 2.5- 7.5 mps