J9.2 FIELD AND LABORATORY DISPERSION STUDIES OF BUOYANT PLUME RELEASE IN AN URBAN ENVIRONMENT

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1. INTRODUCTION

Stemming from the Western U.S. Energy Crisis in 2000 and 2001, movements towards power independence from the grid have risen for hotels, hospitals, restaurants, businesses and schools. One of the solutions is to install on site small scale power generators, known as distributed power generators (DGs). Although beneficial to local industries by providing power independence, questions have been raised towards the localized air quality impacts caused by these DGs. DG technology has led to the necessity for studies of elevated buoyant plume dispersions in urban environments.

Field studies were conducted for a DG facility located at Sunrise Park in Palm Springs, CA. Tracer gas was released with stack exhaust and collected via 49 sampling stations positioned in arcs surrounding the DG. Meteorological data including wind velocity, temperature, heat flux and radiation were also recorded. Field measurements were scaled down for laboratory experiments in a water channel at the Laboratory for Environmental Flow Modeling at the University of California, Riverside. Laboratory modeling was validated using the field measurements. Several more experiments were conducted to explore the influence of building effects of added simple arrays.

2. FIELD MEASUREMENTS

The field dispersion study was conducted at Palm Springs in July 2008. SF_6 tracer gas was released from the 10 meters tall stack of 650 kW DG located in the center of Sunrise Park, Palm Springs, California. Ground level concentrations (GLCs) taken at height of 2 meters were measured from 49 sampling stations located on 100m, 400m, 1km, 2km and 4 km arcs from the DG. The locations of sampling sites are mapped in **Error! Reference source not found.**. Experiments were conducted for a total of 6 days: 3 days for daytime and 3 days for nighttime releases. Hourly concentration measurements were done for each 6 hour release session. Meteorological equipment was stationed on a 10m tall tower and was located in a nearby parking lot and on a tripod located on the roof of the DG facility.

3. LABORATORY

3.1 Water Channel

At the Laboratory of Environmental Flow Modeling at the University of California, Riverside, a scaled-down model of the DG was created in a water channel. The water channel test section is 3 meters long, 1 meter wide and 0.5 meters deep. The flow rates are controlled via 20HP axial pump capable of achieving a maximum of 0.5m/s mean velocity in the test region. Mean velocities in the test section are controlled by a variable frequency controller that varies from 0 to 60 Hz with .01 Hz resolution. More details of the experimental setup are given in Princevac et al. (2009). In order for the DG model to be useful to predict real world GLCs, parameters from field were used to fulfill geometric, kinematic, and buoyancy similarities. In the next section the similarities used for laboratory modeling are discussed.

3.2 Similarity and Scaling

Geometric similarity is satisfied by keeping length scale ratios same for field and laboratory situations as

$$\frac{D_f}{H_f} = \frac{D_l}{H_l} \tag{1}$$

where *D* is the source stack diameter and *H* is the stack release height. The subscript f indicates field parameters and l indicates laboratory parameters. Next, kinematic similarity was satisfied by keeping ratios of the stack exit velocity (V) and the oncoming downwind velocity (*U*) the same in field and laboratory situations as

$$\frac{V_f}{U_f} = \frac{V_l}{U_l}. \tag{2}$$

To satisfy the buoyancy similarity we keep the final plume rise normalized by source release height the same for laboratory and field as

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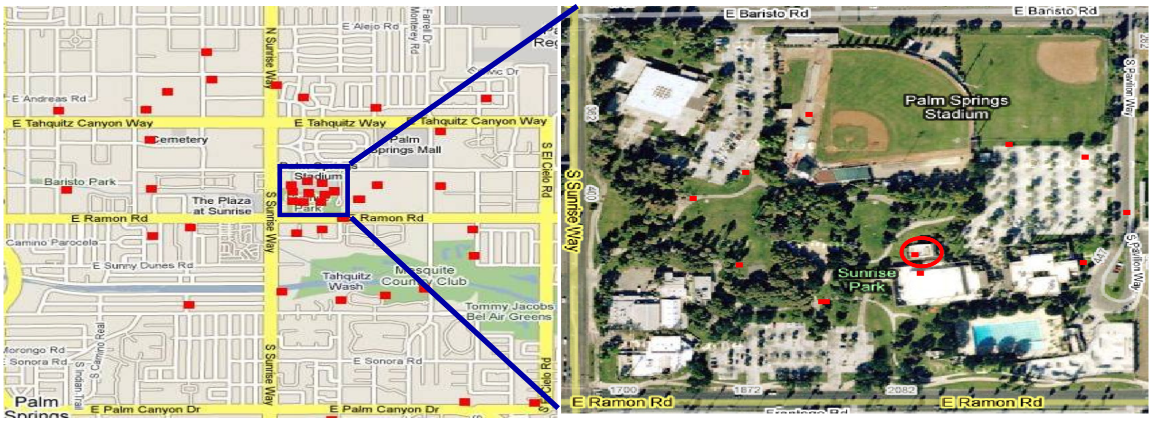

Figure 1: The figure to the left displays a map of the Palm Springs area and sampling locations in the field of study (red squares). The figure to the right is a satellite image of Sunrise Park where the DG is located. The DG facility is circled in red.

$$\frac{\Delta h_f}{H_f} = \frac{\Delta h_l}{H_l} \tag{3}$$

where, Δh is the final plume rise. The final plume rise is estimated using

$$\Delta h = 1.8\frac{F}{U\sigma_w^2} \tag{4}$$

where, F is the buoyancy parameter and σ_w is the fluctuation (rms) of the vertical velocity. In the field, buoyancy results from temperature difference between the exhaust plume and ambient air as

$$F_f = \frac{gVD^2}{4}\frac{T_s - T_a}{T_s} \tag{6}$$

where g is gravity, T_s is the exhaust exit temperature, and T_a is the ambient temperature. However, for water channel simulations, the temperature differences are difficult to control due to numerous heat losses that occur while pumping the dye to the mock DG facility in the water channel. For this reason, solutions of water and alcohol were used to modify the buoyancy parameter for laboratory conditions. The buoyancy force for laboratory can be calculated as

$$F_l = \frac{gVD^2}{4}\frac{\rho_a - \rho_s}{\rho_a} \tag{5}$$

where ρ_a is the ambient density and $\rho_s$is the density of mixture released from the source.

Dilution is defined as a ratio of the observed concentration to source strength.

$$d = \frac{C}{C_0\dot{Q}} = \frac{C}{C_0V\left(\frac{\pi}{4}D^2\right)} \tag{6}$$

where C is the observed concentrations, and C_0 is the source concentration. The non dimensional concentrations for both lab and field measurements should be equal.

$$\left[\frac{C}{C_0}\right]_f = \left[\frac{C}{C_0}\right]_l \tag{7}$$

Field dilution is calculated by multiplying laboratory dilutions with kinematic similarity and the geometric similarity squared as

$$d_f = d_l\frac{V_l}{V_f}\left(\frac{D_l}{D_f}\right)^2 \tag{8}$$

3.3 Laboratory Measurement Techniques

Velocity and concentration measurements in laboratory experiments were collected via Particle Image Velocimetry (PIV) and Planar Laser Induced Fluorescence (PLIF) techniques (Crimaldi 2008). Eliokem Pliolite Ultra 1000 particles, with mean diameter of 50µm served as tracers in the PIV system. Fluorescent Rhodamine B dye was mixed with the stack exhaust solution and was used for PLIF system. Planes of interest were plume centerline (y=0) directly downstream from the stack source. Images were captured at 1Hz for 120 seconds by 11MP and 2MP cameras for PIV and PLIF, respectively. The PIV and PLIF image capturing, as well as image processing, were managed by the TSI Insight 3G package.

3.4 Model Configurations

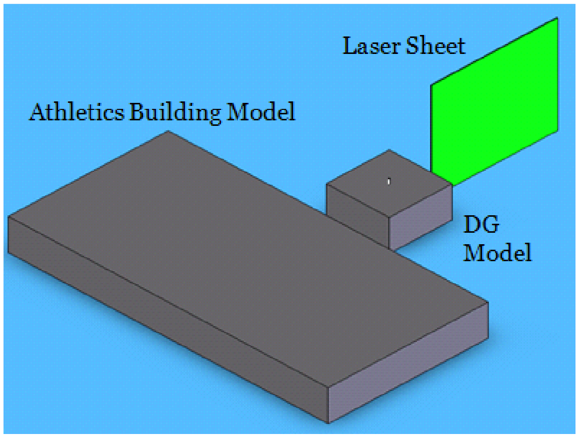

Figure 2: Palm Springs Model

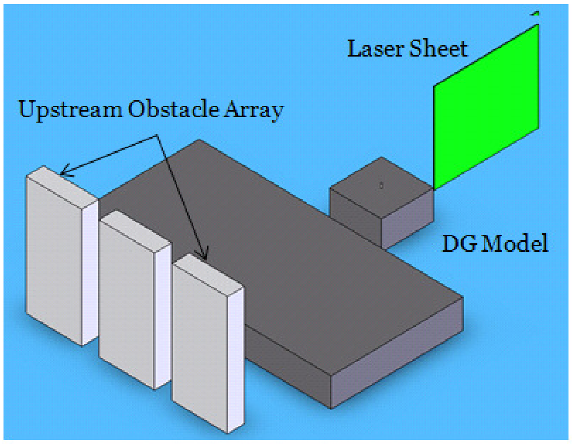

Figure 3: Upstream perturbation setup

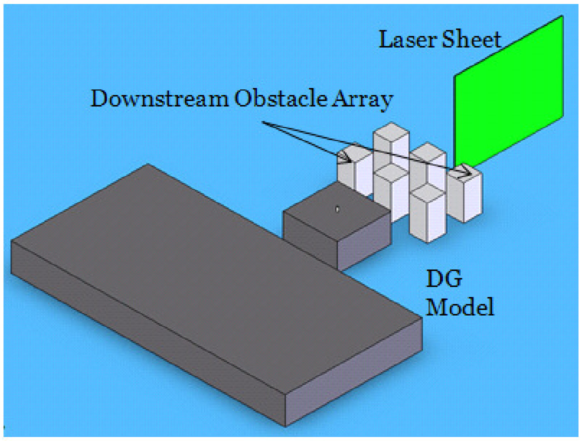

Figure 4: Downstream perturbation setup

The Palm Springs DG site was modeled in the water channel in 1:83 scale. The two most significant buildings in the area are the DG facility housing the generator and an athletic center located directly upstream (south) from the DG facility. The two buildings were scaled accordingly as shown in **Error! Reference source not found.**. Laser sheet was aligned at various downstream distances from model DG on the plume centerline plane aligned with the south - north wind direction.

To investigate the influence of simple structural arrays on plume dispersion, two configurations were created and placed upstream and downstream from the Palm Springs setup. The first form of perturbation tested was a 1x3 tall building array with heights 4 times larger than the DG model in **Error! Reference source not found.**. Next tested setup involved a 2x3 building array downstream from the stack source with heights comparable to the DG facility in **Error! Reference source not found.**.

4. RESULTS

4.1 Buoyancy study

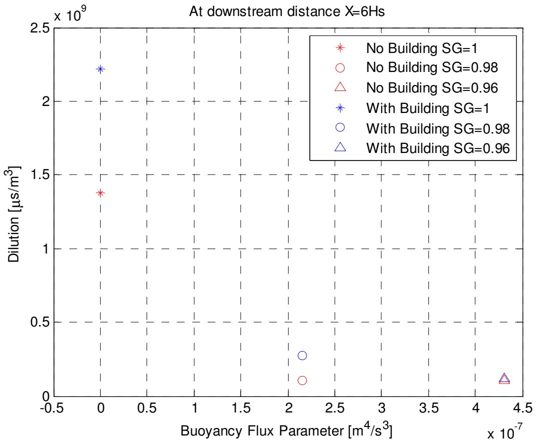

Figure 5: Influences of the buoyancy parameter on dilution

The buoyancy effects and the addition of an isolated obstacle downstream from a simple stack on GLCs were investigated. First, experiments were executed using three separate buoyancy parameters on a simple stack and second, the experiments were repeated after the addition of an isolated downstream obstacle. Concentration measurements were taken at 6 stack heights downstream. Laboratory results indicate a decrease in concentrations as the buoyancy parameter is increased. Experiments with the addition of an isolated block of comparable height placed half a stack height away from the source displayed increased GLCs in comparison with experiments without the obstacle at close ranges. However as the buoyancy parameter increased the effect of the building became negligible (Figure 5).

4.2 Palm Springs Model

To verify our scaling parameterizations, results from Palm Springs field measurements were compared to the laboratory model in Figure 6. The x-axis shows the distance from sampling location to the source and the dilutions are presented on the y-axis. The plot shows field measurements for three experiments of the field study on the 15th, 16th, and 17th of July 2008 and 2 runs of PLIF Far Field Runs (PFFR1 and PFFR2). It is important to note that the laboratory measurements are consistently higher than those from field measurements, because the field measurements were taken in arcs around the source unlike the laboratory where the measurements were taken directly at the plume centerline downstream from source.

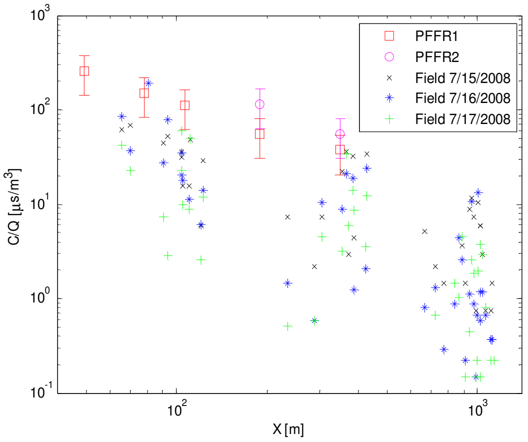

Figure 6: Field and laboratory scaled dilution in the far field

4.3 Near Field Model

The next set of experiments focused on ranges within 100m from the Palm Springs DG facility with and without the upstream and downstream perturbations. Concentrations were captured at three ranges downstream from the source for each setup. Using the dilution scaling the results of the laboratory experiments were scaled to expected dilutions in the field and plotted in 7.

Laboratory parameters were based on data observed on three daytime field releases under similar conditions. The field data show maximum, 1hr averaged, concentrations. . Most field study sampling stations were not located directly downstream of the source release and should predict lower concentrations compared to the scaled model. These results specifically used the centerline plane of the plume in which the largest concentrations are expected.

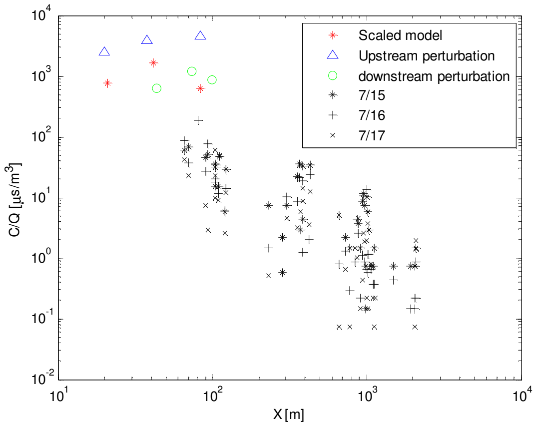

Figure 7: Field and laboratory scaled dilution in the near field

Higher concentrations observed in the upstream perturbation case are attributed to the effects of the large structures on the velocity field. PIV measurements were taken of the Palm Springs model and the upstream perturbation at various downstream distances. An example of PIV results can be seen in figure 8.

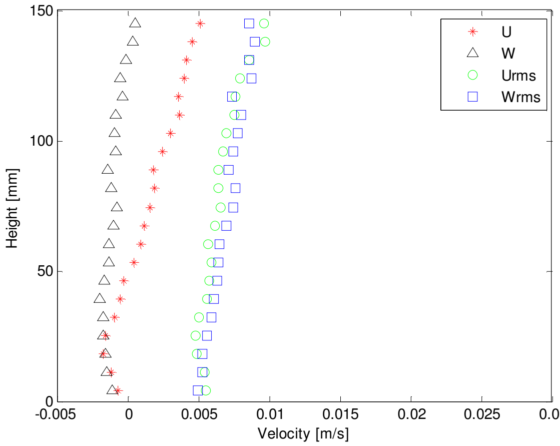

Figure 8: PIV results for upstream perturbation taken 2 stack heights downstream from source

PIV results conveyed that the tall building decreases the *U* velocity and U_{rms} compared to the non perturbed case. Further, the decrease in *U* velocity and U_{rms} is greater at closer ranges. In contrast to the horizontal velocity fluctuations, the vertical velocity and fluctuations appear to be undisturbed. The turbulent intensity, defined as

$$I = \frac{w_{rms}}{U'} \qquad (9)$$

The turbulent intensity greatly affects the turbulent mixing of the pollutants and may be the reason for higher GLC observed in the experiments. The turbulent intensity without perturbation is approximately 33%. After adding the tall building perturbation the turbulent intensity for far and near source positions becomes 66% and 200%, respectively. The greater vertical spread of the plume relative to distance traveled may cause the plume to touch down earlier producing higher concentrations at closer distances, as was observed in the laboratory experiments.

Table 1: Summary of Turbulent intensities

Case	Turbulent Intensity
Palm Springs (2xHs)	33%
Upstream Perturbation (10xHs)	66%
Upstream Perturbation (2xHs)	200%

A difference between the Palm Springs setup and the downstream perturbation was also observed in the laboratory experiments. Plume dispersion visualizations were done for the downstream perturbation setup. Visualizations indicated that the complex downstream array increases laterals dispersion decreasing the concentrations directly downstream on the plume centerline. Experiments with single obstacle suggest that a downstream perturbation should increase the observed GLCs, however the downstream array lead to concentration decrease.

5. SUMMARY

A field and laboratory dispersion study was conducted. A method for satisfying geometric, kinematic, and buoyancy similarities was presented and used for scaling laboratory results to field scale. Alternative buoyancy production method in laboratory by mixing alcohol and water based dye was used to investigate plume buoyancy effect on GLC. Experiments showed that a single downstream obstacle will lead to increase in GLC, however this influence diminishes as plume buoyancy increases. Downstream array of buildings will lead to lateral channeling of plume, higher horizontal spread, which results in lower GLC.

6. ACKNOWLEDGEMENT

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