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A WIND-TUNNEL STUDY OF EXHAUST STACK EMISSIONS FROM THE NATIONAL TRITIUM LABELING FACILITY LOCATED AT LAWRANCE BERKELEY NATIONAL LABORATORY, BERKELEY, CA

Bruce R. White*
Rachael Coquilla*
Bethany Kuspa*Jim Phoreman*

*University of California, Davis
Department of Mechanical and Aeronautical Engineering
One Shields Avenue, Davis, California 95616-5294
brwhite@ucdavis.edu

ABSTRACT

A wind-tunnel study was conducted to simulate stack releases of tritiated water vapor (HTO) from the National Tritium Labeling Facility (NTLF) of the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL). Physical modeling simulations were performed in the Atmospheric Boundary Layer Wind Tunnel (ABLWT) at University of California, Davis. A circular-based scaled-model (1:800) of the site represented a full-scale area of 3,000 feet (914 meters) in diameter, including all buildings, topography, and the relative tree cover. The model was also turntable mounted so that it could be rotated to any desired wind direction. Stack effluent was modeled by releasing a neutrally buoyant tracer gas (ethane) from the scaled model exhaust system. Simultaneously, concentration (or dilution) levels of the dispersed emissions at specified downwind ground-level receptor sites were measured using a hydrocarbon gas analyzer. The wind tunnel simulated near-neutral atmospheric conditions (between stability category B and C of the Pasquill-Gifford categories). Tests were conducted over a wide range of wind regimes that dynamically matched full-scale speeds ranging from a few mph to speeds in excess of 25 mph.

INTRODUCTION

This report documents a wind-tunnel study of the release of tritiated water vapor (HTO) from a previously existing and proposed exhaust stacks located at the National Tritium Labeling Facility (NTLF). The study was primarily driven by the interest of where to appropriately locate proposed air monitoring stations. Results from this study would provide physical modeling information for positioning proposed tritium monitoring stations. The existing stack is 9.14 m (30 ft) tall and 1 m (3.28 ft) in diameter (see Figure 1). It is solely situated on the hillside slope of the Eucalyptus Grove above and to the west of NTLF Building 75 and is surrounded by numerous tall Eucalyptus trees. The proposed stack is to be constructed on the rooftop of Building 75 with a height of 4.57 m (15 ft). Both stacks are bordered by steep topographic inclines spanning from west to east. A photograph consisting of the existing stack and the location of the proposed stack is presented in Figure 2. The main objectives of this investigation is to assess the nature of the local flow effects due to the complex terrain features of the Berkeley hills and to estimate the magnitude of concentrations dispersed from the source stacks.

Figure 1: Site Photo of Existing Stack Located Inside Eucalyptus Grove Hillside.

Figure 2: Site Photo of Existing Stack and Proposed Location of Building 75 Stack.

Comparison of Atmospheric Modeling Techniques

Environmental assessment of an exhaust stack can be approached in three different techniques: numerical modeling, full-scale tests, or wind-tunnel simulation. Numerical models, dispersion models in particular, incorporate semi-empirical theory that generally leads to reasonable predictions of concentration levels around and even beyond the vicinity of the source emission. Many numerical models are also limited by failing to account for the local effects of nearby obstacles and of complex topography or by requiring locally measured turbulence data. Full-scale dispersion tests provide useful data for determining true concentration levels. However, conducting full-scale tests for numerous wind directions and wind speeds is relatively impractical.

Physical modeling in a wind tunnel has great potential for the simulation of atmospheric boundary layers. A model of the site of interest is placed in a wind tunnel where wind-speed and dispersion measurements can be taken. This modeling technique can be an efficient means of obtaining reasonable estimates of a desired data while properly accounting for local flow around obstacles and turbulence characteristics of the full-scale flows.

Wind-tunnel testing could also be utilized for physically simulating the flow field over highly complicated terrain conditions such as the hills around the LBNL. For terrain with complex topography, where the height changes in the order of the height of the release stack, both physical and/or numerical simulation techniques required the input of additional field measurements, especially meteorological measurements on the site. On-site wind speed, wind frequency, and atmospheric stability measurements are very important for the accurate simulation whether it is numerical or physical in nature. However, the ability of physical modeling to simulate the turbulence characteristics of the flow over small-scale terrain features in nearly neutral flow is still considered superior to available numerical models. Therefore, physical modeling can be helpful in the process of evaluating the dispersion process from a source stack. The only drawback is that the wind tunnel used in the current investigation did not simulate non-neutral atmospheric conditions that can add substantial effects on the nature of the dispersion process.

Wind-Tunnel Atmospheric Modeling Parameters Emphasizing Complex Terrain

The present wind-tunnel investigation was performed in the Atmospheric Boundary Layer Wind Tunnel (ABLWT) located at University of California, Davis (UCD). A detailed description of the facility is given in Appendix A. Testing was conducted using a 1:800-inch scaled-model built on a 1.15-m diameter turntable base and centered on the site of the existing exhaust stack. Figure 3 presents a photo of the model installed inside the wind tunnel test section. In full scale, the model would encompasses an area with a diameter of 3,000, which includes not only buildings of the national laboratory but also the Lawrence Hall of Science, the Math Sciences Research Institute, and the Space Science facilities, as well as all tree groves contained within the area. A small model scale was chosen due to the complexity of the terrain.

Figure 3: Wind Tunnel Scaled Model of the Berkeley Hills with the Lawrence Berkeley National Laboratory.

By normalizing the time-averaged equations of fluid motion, similitude parameters are given by the Rossby number, the Densimetric Froude number, the Prandtl number, the Eckert number, and the Reynolds number. Application of these non-dimensional quantities along with their host equations of motion can describe atmospheric flows over all types of terrain conditions, including those that are complex in nature. Based on an analysis of the similitude parameters presented in Appendix C, only the critical Reynolds numbers related to boundary-layer dynamic similarity are important for the current wind tunnel modeling (given that the targeted simulated flow is neutrally stable and corresponds only to the lowest hundred meters of the atmosphere). Thus, for the current investigation, the Rossby number similarity is neglected since effects of upper atmospheric motion, driven by the earth's rotation, become insignificant for length scales less than five miles. Froude number matching is ignored for neutrally stable conditions. The Prandtl number already matches since the fluid media is identically air. The Eckert number is excluded since the modeled and full-scale flows are incompressible.

Wind-Tunnel Atmospheric Boundary Layer Similarity For Complex Terrain

Physical modeling of the complex terrain was additionally limited by the required atmospheric boundary-layer similarities and by the physical size constraints of the wind-tunnel test section. Analysis of such modeling conditions is presented in Appendix D. A circular turntable model can easily encompass the entire 1.18-m width of the test section. However, geometric scaling was restricted given two critical conditions: i) the highest point on the model is maintained within the wind tunnel boundary layer region that meets full-scale similarity; and, ii) the model cross-sectional area facing the incoming flow does not cover more than 15% of the test section cross-section so as to prevent pressure-gradient driven flow.

Boundary-layer similarities were satisfied by the long flow development design of the ABLWT. With the use of triangular spires and the distribution of roughness elements, a fully developed aerodynamically rough boundary layer is generated at the test section. For a free stream wind tunnel speed of 4.0 m/s, the boundary layer grows to a height of about one meter at the test section, in which the logarithmic wind profile region is in the lowest 20%. Since this region is the only portion of the wind-tunnel boundary layer that is dynamic similar to the surface region of the atmosphere, the first requirement suggested that the model be scaled so that the highest peak of the terrain is no higher than 0.2 m. If the model diameter was equivalent to the test section width, a 0.2-m height limitation provides a model cross-sectional area much less than 15% of the test section cross-section.

The main objective of the wind-tunnel study was to trace the resulting concentration distribution due to the effects of complex topography, a model representing the largest full-scale area that essentially includes the most dominant terrain features was initially considered. Thus, the turntable model was constructed on a 1.15-m diameter base, spanning the test-section width. Considering the size and similarity constraints, the wind tunnel model was geometrically sized using a 1:800-inch reduction. Centering on the UC grid coordinates, 3500E and 500N, which is near the location of the existing stack, the wind tunnel model depicted a circular full-scale area 3000 ft. in diameter. Although, the wind tunnel model can represents only a few kilometers of the regional topography, it still captures the most distinct land features that could contribute significant local dispersion process of stack emissions. Wind-tunnel simulation can be a useful tool in the analysis of the dispersion process within a complex terrain region such as the hills around the LBNL.

Wind-Tunnel Stack Emission Dispersion Modeling

Stack emissions were modeled using a neutrally buoyant, hydrocarbon tracer gas. By monitoring hydrocarbon concentration levels with an ion flame detection system, the dilution of the stack emissions was determined at a measured receptor location. The scaling was accomplished by maintaining the momentum ratio of the vertical exhaust effluent to the horizontal wind speed, at the stack height and location, constant between full scale and the wind-tunnel simulation. To insure a fully turbulent discharge, a tripping device was incorporated in to the model exhaust stack. The full-scale meteorological data, acquired on 20-meter tower near Building 44, used in the following manner to determine the wind speed at which the model test was to be conducted. The wind speed and direction, in the tunnel, was set to model the full-scale conditions at the meteorological tower, the wind speed then was measured in the wind tunnel at the model stack location and height. Note, this value could be substantially different from the speed observed at the metrological tower due to the affect on the complex terrain on the wind flow patterns. Thus, it was essential to correlate the relationship between the metrological tower speed and direction to that of the speed and direction the wind at the top of the stack being measured. This correlation data was measured for all 16 major wind sectors used in the annual average analysis and the wind-tunnel settings made according to the results of the correlation.

WIND-TUNNEL TESTING AND ANALSIS

Wind tunnel simulations were divided into three test phases. An initial test was performed to examine the horizontal dispersion of the exhaust plume downwind of the source stack. In the second phase, concentrations were collected over a grid network of 49 points around the emission source, representing a 600-ft by 600-ft square area. For the third phase, measurements over a larger grid system that encompassed the entire wind-tunnel turntable model were conducted for estimation of annual average exposure levels.

Complex Terrain Effect on Stack Dispersion

In the first phase of wind tunnel simulations, the downwind dispersion of emissions from the existing stack model was traced to determine the combined effects of angular wind offset and of the surrounding complex terrain. Wind speeds at the stack height were simulated based on equivalent full-scale magnitudes of 2.5, 5, and 20 mph. According to atmospheric field data recorded from a nearby 20-m meteorological (MET) tower located at LBNL Building 44, local wind speeds routinely range from 0.5 to 20 mph.

Due to the complex terrain in which the LBNL is situated, exhaust dispersions may not always be Gaussian where the downwind peak concentrations could be off centerline from the direction of the incoming wind angle. Located on the map in **Error! Reference source not found.** are four test point locations found to be useful for examining concentration measurement sensitivity.