REPRODUCING A SECTION OF THE EARTH'S ATMOSPHERIC SURFACE LAYER IN SMALL WIND TUNNELS FOR STUDIES ON THE ENVIRONMENTAL FATE OF CHEMICAL WARFARE AGENTS

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ABSTRACT

Vapor and contact hazard tracking with computer models is critical to the commander after a Chemical Warfare Agents (CWA) attack. The Agent Fate Program is providing the database of measurements for developing these hazard prediction models. Wind speed is one of the environmental variables controlling CWA volatilization, therefore, an accurate flow field over the CWA droplets or droplet wetted area had to be designed into small laboratory wind tunnels. The wind tunnel boundary-layer (BL) measurements with atmospheric BL theoretical predictions and examples of CWA evaporation results will be presented in this summary.

1. INTRODUCTION

Developing accurate modules for secondary chemical contamination for computer models such as VLSTRACK, depends on establishing an understanding of the underlying physical processes associated with the volatilization of hazardous chemicals under environmental conditions. Variables that control the evaporation and desorption of liquid contaminants include wind speed, along with temperature, relative humidity, drop size, the CWA type (G-agent, V-agent, vesicant), and material surface type (concrete, asphalt, soil). The data required to validate these models can be obtained at several different scales; each scale contributes to accurate measurement databases and models. Limited-scale field-testing is the largest scale feasible with toxic CWA. Field testing allows close to full scale testing in the planetary surface layer under typical meteorological conditions; however, the inability to control the environmental conditions causes problems with determining interdependency of wind speed, temperature, and humidity on volatilization rates. A large-scale, enclosed environmental wind tunnel is also part of the Agent Fate Program. Finally small-scale laboratory wind tunnels can be employed, both of which can fit inside a CWA fume hood. These experimental devices are a reasonable size for analytical vapor sampling techniques and require only one droplet of the toxic chemical. Due to their small size, special care is required in their aerodynamic design to tailor their internal BL profile to match a small portion of the atmospheric BL. (Weber, et.al. 2003a, 2003b)

2. EXPERIMENTION: WIND TUNNELS

The Agent Fate program is developing two types of small wind tunnels, microbalance and vapor-sampled wind tunnels, both of which are designed for single agent droplets. Two versions of the microbalance wind tunnel (MBWT) are commercial Thermal Gravimetric Analyzers (TGA) and have had their flow fields characterized above the sample pans for a range of flow rates. One model of the MBWT has a single sample pan, while the other has two pans, allowing one substrate to serve as a reference during testing. The vapor-sampled wind tunnel resembles the classical wind tunnel design with a 5x5-cm test section. This tunnel is shown in Fig. 1.

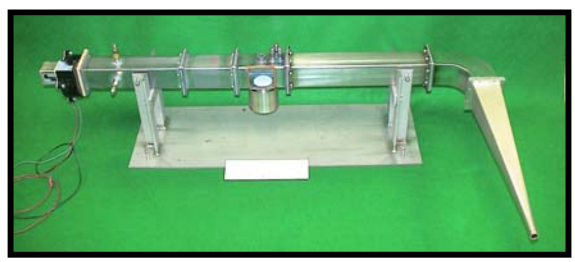

Figure 1 5x5-cm Agent Fate Wind Tunnel

3. ATMOSPHERIC BOUNDARY LAYER

It should be emphasized that the droplets, surface materials, and velocity profiles are not scaled for these tests. The droplet and substrates are full size, which leads to the challenging problem that the velocity field inside the wind tunnel must match the atmospheric wind profile, especially near the droplet. Because the wind tunnel cross-sections are small, the goal is to match the atmospheric profile within a centimeter of the drop, thus matching the surface shear stress. The lower part of the atmospheric BL is made up of three regions: a laminar sublayer next to the ground (nearest the drop), a buffer region above the sublayer which then transitions into the turbulent region. For the present case, the surface is assumed to be smooth which is reasonable for substrates

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such as metal, glass, sand/soil, concrete and asphalt. Eq. 1 defines the velocity in the laminar sublayer, while Eq. 2 also known as the "Law of the Wall" describes the velocity in the turbulent region. (Potter and Foss, 1982),

$$u/u^* = u^* z/\nu \tag{1}$$

$$u/u^* = (1/\kappa)\ \ln(u^* z/\nu) + B \tag{2}$$

where u is the local wind speed at height z above the surface, u* is the friction velocity which is proportional to the surface shear stress, ν is the kinematic viscosity of air, κ is the Von-Karman constant (usually = 0.4), and B is a constant (usually = 5.5).

Eqs 1 and 2 were used to determine the theoretical atmospheric profiles that the experimental wind tunnels were targeted to approximate. Hotwire anemometry and/or Computational Fluid Dynamics (CFD) were employed to measure the centerline test section profiles in each wind tunnel device. A comparison of these results for the single pan MBWT and the 5x5-cm wind tunnel are shown in Fig. 2 and Fig. 3, respectively. Overall, the agreement is very good.

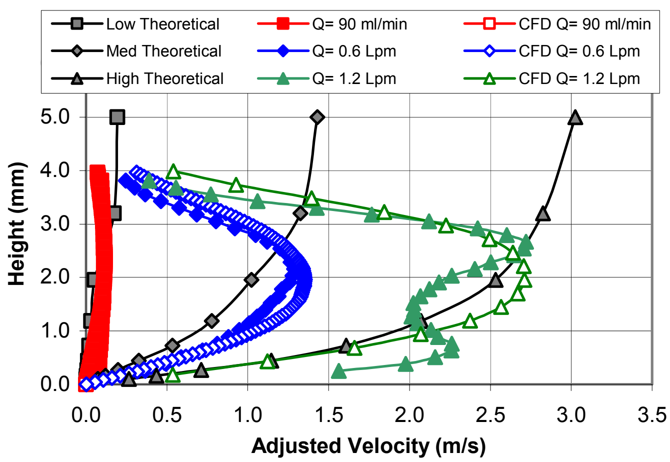

Figure 2 Single Pan TGA Profile Comparison

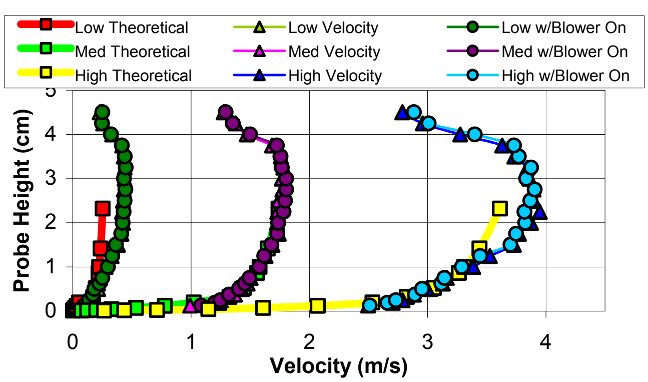

Figure 3 5x5-cm Velocity Profile Comparison

4. EXPERMENTAL RESULTS

Over 100 CWA experiments have been performed with the MBWT. An example for CWA HD on 2024 aluminum (C17 Cargo Ramp) from the dual pan MBWT is shown in Fig. 4 comparing the influence of wind speed with other conditions held constant. Flow rates of 100 and 1000 mL/min through the MBWT correspond to wind speeds at a 1mm height of ~0.003 and 0.03 m/s (0.011 and 0.11 kph). These velocities correspond to a 2.0 m height velocity of 0.15 and 0.5 m/s, respectively. Therefore, a factor of ~3 difference in wind speed (at 2 m) yields a factor of ~1.7 difference in the time to complete evaporation.

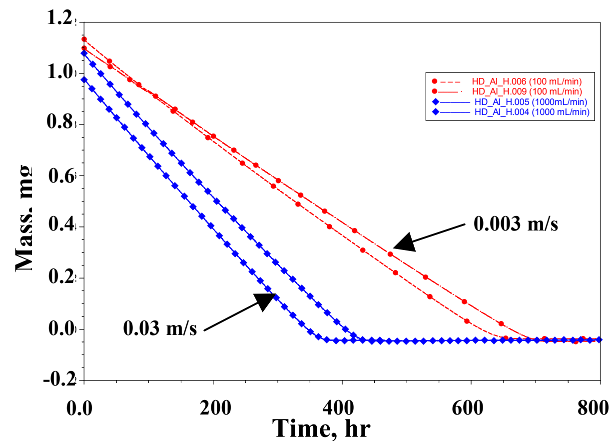

Figure 4 Dual Pan MBWT (TA Q600), 15% RH, 15 °C

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Weber D. J., J. W. Molnar, M. K. Scudder, and W. J. Shuely, 2003b: Characterization of the flow field and wind speed profiles in microbalance wind tunnels for measurement of agent fate. Conference Proceedings for the Joint Service Scientific Conf. on CB Defense Research, Towson, MD, U.S. Army ECBC

CONCLUSION

In support of the Agent Fate program, the wind tunnels' centerline velocity profiles have been estimated by hot wire anemometry and CFD and compared to atmospheric surface layer predictions. Evaporation experiments with CWA from different material surfaces are being conducted with wind speed assignments based on these velocity profile measurements.