Static Pressure Requirements for Ventilated Enclosures

Heitbrink W A[1], Thimons E D[2], Organiscak J A[2], Cecala A R[2], Schmitz M[3], Ahrenholtz E[3]
[1]U.S. Department of Health and Human Services (DHHS), Public Health Service (PHS), Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH), Ohio, USA
[2]U.S. DHHS, PHS, CDC, NIOSH, Pennsylvania, USA
[3]Clean Air Filter, Iowa, USA

Environmental enclosures on vehicles protect workers from pesticide exposures during air blast spraying and dust exposures during surface mining operations.(1) One or more fans draw air through filters to remove air contaminants and force clean air into an enclosure at some minimum static pressure. Air flows out a cab through either a baffled outlet port or leaks in the enclosure. Enclosures also have holes for electrical and mechanical connections. Because the vehicles are used in open environments, ambient wind may cause air infiltration to increase when the wind's velocity pressure is greater than the static pressure in the enclosure. Thus, the effects of velocity pressure and enclosure static pressure upon the exposure reduction obtained by an idealized enclosure were evaluated.

Air flow through holes in an enclosure can be modeled as air flow through an orifice. From a mechanical energy balance (Bernoulli's equation), a formula relating the air velocity in a hole or orifice in an enclosure to the velocity pressure of the wind and the static pressure in an enclosure is as follows:(2)

$$v_o = 0.61\sqrt{2(0.5\rho v_1^2 - p)/\rho} \quad (1)$$

Where:

v = air velocity subscripts: 1-outside the enclosure, o-in the orifice (m/sec);
p = static pressure inside the enclosure (kg/m/sec^2); and,
ρ = density of air (kg/m^3).

This equation resembles the equation for the flow of an incompressible fluid through a sharp-edged orifice.(3) In the $0.5\rho v_1^2$ formula, is the wind's velocity pressure. The infiltration air flow is the product of vo and the area through which the fluid flows. For air to enter the enclosure, the wind's velocity pressure must be greater than the enclosure's static pressure.

Experimental Procedures

To evaluate this static pressure criteria, the effect of wind upon aerosol penetration into a simulated enclosure was studied experimentally. An ultralight aircraft blew air around a simulated enclosure. The effect of wind speed upon enclosure static pressure and aerosol penetration into the enclosure were measured.(4) The wind speed was varied by

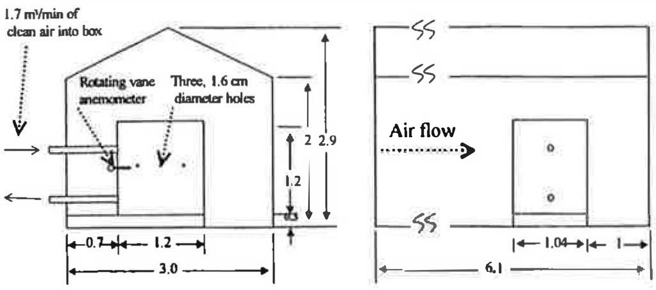

Figure 1. Schematic of test stand, dimensions are in meters

changing the aircraft's engine rpm and the distance from the front of the simulated enclosure. The air flow from the ultralight aircraft was directed through a tunnel containing a simulated enclosure (see Figure 1). The simulated enclosure had three 1.6 cm diameter holes in the front (facing the wind) and rear faces. Two fans (Model 3540, Jabsco, Costa Mesa, California) were used to pressurize the inside of this box. The fans pulled air through a filter and discharged the air through a second filter, through a 7.5 cm diameter pipe, and into the box. The filters (GL910, Clean Air Filter, Defiance, Iowa) contained media that was 99 percent efficient against 0.3 µm particles. The air flow into the enclosure was 1.7 m3/min at a static pressure of 2.8 mm of water. The air flow was measured using a six-point pitot tube traverse.

During each experimental run, static pressures were measured with an electronic manometer (Model MP20SR, Neutronics, Herts, United Kingdom). A rotating vane anemometer (Model HTA4200, Pacer Industries, Chippewa Falls, Wisconsin) was used to measure wind speed near the holes in the enclosure every 15 seconds. Two optical particle counters (Grimm PDM, Model 1106, Ainring, Germany) measured the number concentration of particles between 0.35 to 0.5 µm inside and outside the enclosure. Aerosol penetration into the cab was the ratio of the concentration inside the enclosure to the concentration outside.

Results

Wind velocity affected aerosol penetration into the enclosure, and it caused enclosure static pressure to increase slightly from 2.8 to 3.2 mm of water as wind speed increased from 15 to 35 km/hr. In Figure 2, observed penetration is plotted as a function of air velocity as measured by the rotating vane anemometer. The average velocities have coefficients of variation of 10 to 20 percent. Under calm conditions, aerosol penetration into the enclosure had an upper 99 percent confidence limit of 0.003. For air velocities larger than 20 km/hr, the measured penetration exceeded 0.003, and it increased linearly with air speed. Based upon an enclosure static pressure of 2.8 mm of water, air velocities above 24 km/hr were expected to cause increased penetration into the cab. Because air velocities were variable, some

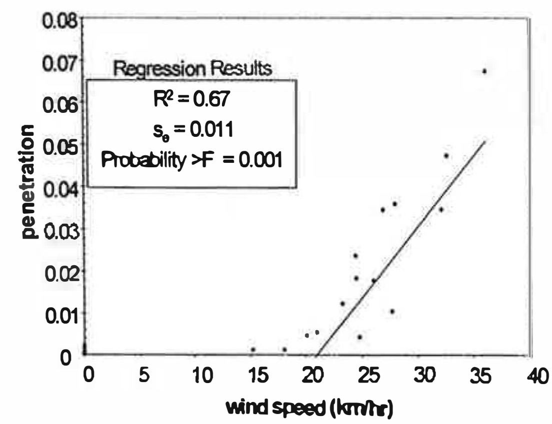

Figure 2. Penetration increases with average wind speed above 20 km/hr

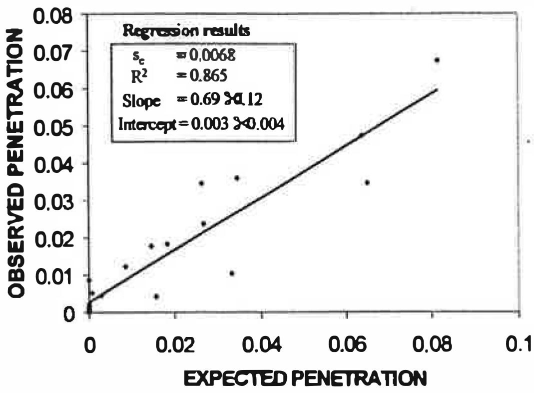

Figure 3. Observed penetration as a function of expected penetration

individual velocity measurements exceeded the expected threshold velocity, and penetration may have occurred during a fraction of the sampling period. To examine the accuracy of Equation 1, the air flow through the three orifices was estimated from the area of the orifices and the estimated orifice velocity using Equation 1. The measured enclosure static pressure and air velocities around the enclosure were used to estimate the orifice velocity for each air velocity measurement. The expected penetration into the enclosure is the ratio of the expected air flow through the three holes to the flow of filtered air into the enclosure. As shown in Figure 3, the observed penetration is a linear function of the expected penetration into the enclosure. However, the expected penetration overestimated the observed penetra-tion by 30 percent.

Discussion and Conclusions

The results in Figures 2 and 3 are consistent with the hypothesis that contaminant penetration into an enclosure occurs when wind velocity pressure exceeds the static pressure in the enclosure. Environmental enclosure manufacturers should include enclosure static pressure and maximum ambient wind speed as equipment specifications. In their equipment manuals, manufacturers should warn that air contaminant infiltration into enclosures can increase when the enclosure is used in the presence of excessive ambient wind or when the enclosure static pressure is inadequate. Enclosures should be maintained so that adequate static pressure is maintained in the enclosure.

References

1. American Society of Agricultural Engineers. Agricultural Cabs-Environmental Quality. Part 1: Definitions, Test Methods, and Safety Practices. Standard S525-1.1, 1997. St. Joseph, MI.
2. Bird BB, Stewart WE, Lightfoot EN. Transport Phenomena. New York: John Wiley and Sons, 1960; 211_231.
3. McCabe WL, Smith, JC. Unit Operations of Chemical Engineering. New York, NY: McGraw Hill, 1967.
4. Heitbrink WA, Thimons ED. In-Depth Survey Report: Control Technology for Enviromental Enclosures - The Effect of Wind Speed Upon Aerosol Penetration Into An Enclosure. Cincinnati, OH: U.S. DHHS, PHS, CDC, National Institute for Occupational Safety and Health, 1999 (Report No. ECTB 223-15a).