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Wind Tunnel Testing of Open Top Field Chambers for Plant Effects Assessment

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Recent studies have dealt with open top chamber design, construction, and performance.[1–4] These chambers are widely used in efforts to understand damage to crop plants by polluted air and to evaluate economic losses. While much testing of these chambers has taken place in the field, more detailed results can be obtained in a wind tunnel setting. Thus, various field chamber designs were tested using the EPA Meteorological Wind Tunnel at Research Triangle Park, NC. This study was initiated to make detailed measurements of concentration variations within the model chamber under various ambient wind conditions. Another purpose was to determine whether a scale model could provide results comparable to those obtained in the field. If the model had this capability, then the wind tunnel could be used to design and test an improved chamber with the confidence that it would perform similarly in the field.

Information on the meteorological wind tunnel design, construction, and operating characteristics, as well as similarity criteria for fluid modeling is given in Snyder.[5,6] The wind tunnel provides a convenient means to vary many chamber characteristics as well as ambient conditions. While only a few of these factors could be studied in this project, considerable effort was expended to test various baffle angles beginning with the design presented by Kats, *et al.*[3] A nozzle top design by Krupa was also evaluated.[7–9]

Materials and Methods

The model (Figure 1) used in the wind tunnel was scaled by a factor of 10 while maintaining geometric similarity to an

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actual open top field chamber.[1] It measured 300 mm in diameter and 240 mm in height, and was constructed using 7 mil transparent vinyl chloride film placed over a metal frame identical in construction to the full-size chamber. Similarity between inlet hole size, number, and arrangement was also maintained. Air was supplied to the model using a blower with monitored output. This flow rate for most cases was held at approximately 900 L/min.

Ethylene (C_2H_4) was injected into the air stream at a rate of 6.37 L/min to serve as a nonbuoyant trace gas. This gas mixture entered the model chamber in the same manner as is used in the field. The ethylene concentration coming into the chamber was approximately 0.74% by volume. The model was aligned in the tunnel so that the blower box was on the downstream side of the model (Figures 1a and 2).

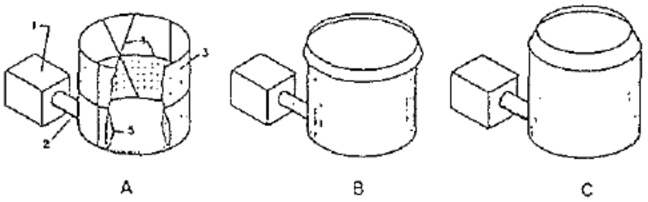

Figure 1. Open top chamber types tested: A. Without baffle, 1) blower box, 2) inlet duct, 3) upper panel, 4) supporting frame, 5) lower duct panel with ports to inside. B. With 45° baffle, C. With nozzle top.

As stated earlier, one major objective was to measure the ingress of outside air by measuring ethylene concentration distributions within the chamber. These measurements were made on a 105-point, three-dimensional grid inside the chamber (Figure 2). Spacing of the grid points was 60 mm in the horizontal and 50 mm in the vertical. Measurements were made in horizontal planes spaced at 25, 75, 125, 175, and 225 mm above the floor of the chamber. Beckman hydrocarbon analyzers* were used to monitor changes in ethylene concentration in the chamber, using 30-sec samples.

It was important in the wind tunnel to provide a surface that would simulate typical field conditions. To accomplish this, 40-mm high blocks were used to obtain a zero-plane displacement height (d) of 20 mm along with a roughness length (z_0) of 5 mm. These values are geometrically similar to field conditions with a displacement value of 20 cm and a roughness length of 5 cm. The parameters d and z_0 were estimated by fitting the observed mean wind profile in the surface (constant flux) layer to the logarithmic profile law. In both the field and wind tunnel cases, the open top chamber was located in the surface layer where the logarithmic profile law holds. Stability effects have not been considered in this study; however, they are not likely to be important to flow within or in the vicinity of the chamber.

Besides the requirements of geometric similarity and surface features, it was also necessary to maintain equal velocity ratios between field and wind tunnel. Preserving these ratios allows confidence in applying tunnel results to the field. These ratios are ambient wind speed (at the height of the chamber top) to the average chamber-top exit velocity, and air speed through chamber inlet holes to chamber-top exit velocity. These latter velocities were calculated from the mixture flow rate and the chamber dimensions. Air exiting from the chamber top does not do so in a uniform manner. Flow visualization indicated that this motion is very complex, with reverse flow in some regions. Nevertheless, by continuity, the velocity calculated above represents the spatial-average, chamber-top exit velocity.

Another parameter for consideration in maintaining flow-field similarity is the Reynolds number.[8] The model Reynolds number was approximately one-tenth the field value in these tests. A full discussion of the problem is beyond the scope of this paper; suffice it to say here that for rounded structures, Reynolds number independence[9,10] is not assured, and validation of these tests will require full-scale experimentation for at least a limited range of parameters for comparison.

Preliminary measurements were conducted in the chamber to determine whether a particular baffle was superior with respect to eliminating the ingress of ambient air. The baffles extended completely around the model chamber (Figure 1b). Baffle angles (from the horizontal) of 15, 45, 60, and 90 degrees were tested. The baffle width was 50 mm and the smaller diameter matched that of the model chamber (Figure 1b). The interior edge of the baffle was located 10 mm above the edge of the chamber. Increases in this distance appeared to have little effect on the ingress of outside air into the chamber. When considering the full range of wind speeds, it was determined that the 45° baffle provided the least dilution of ethylene concentrations inside the chamber. Therefore, this baffle was used in all subsequent testing. A nozzle top chamber[3] (Figure 1c) was also tested. The opening at the top of this chamber was 213 mm in diameter; 91 mm of vertical height was added to the basic chamber height.

Small plastic plants approximately 75 mm tall were used to simulate soybeans in the model chamber. The row configuration is shown in Figure 2. These plants were similar in shape and density to soybean plants, except that they did not bend as easily under the force of the incoming gas mixture as do soybean plants.

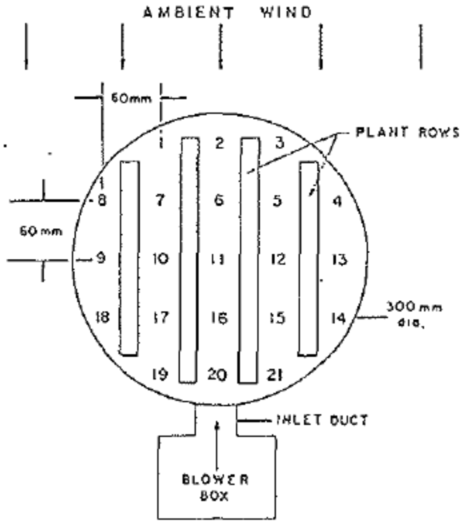

Figure 2. Horizontal sampling positions (indicated by numbers) and plant row layout for all chambers tested.

Results and Discussion

Experimental results are presented in Figure 3. Only the broad scale features of the results will be discussed in this paper. The abscissa of each graph presents the horizontal sampling positions inside the chamber (Figure 2). The ordinate values are ethylene concentration corrected for background level. For visual reference, concentration values in the same row have been connected by a line. The rows (Figure 2) are perpendicular to the tunnel wind direction. Each line on

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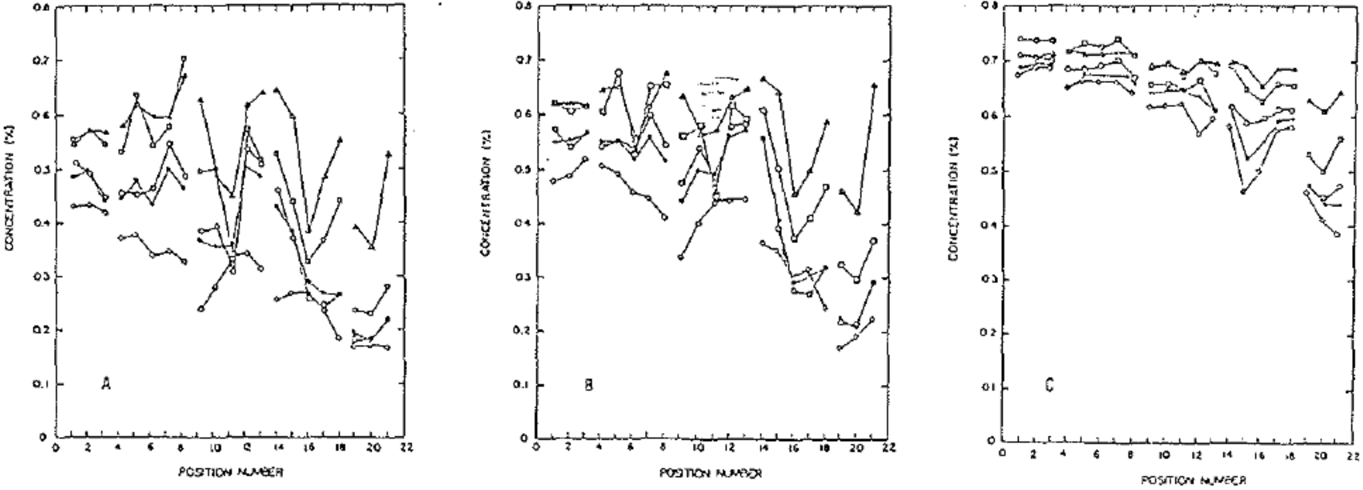

Figure 3. Concentrations of ethylene for 21 horizontal and 5 vertical sampling positions, 25 (△), 75 (□), 125 (O), 175 (⊖), and 225 mm (◇), with the ratio of wind tunnel velocity to chamber exit velocity at 40. A. Open top chamber with plants. B. Open top chamber with 45° baffle and plants. C. Nozzle top chamber with plants.

the graph shows concentrations in the chamber at specified distances above the chamber floor.

The results shown in Figures 3a–3c were for a ratio (ambient wind velocity to chamber exit velocity) of 40. In the field situation, this would correspond to an ambient wind speed of 4.5 m/s, since the best estimate of the field chamber exit velocity is 0.11 m/s.

The results for no baffle and the 45° baffle are shown in Figures 3a and 3b. All testing was done with plants in the chamber. The findings indicate that the 45° baffle has only a small positive effect in reducing the ingress of outside air into the chamber. A potential user of the baffle should carefully weigh whether the slight improvement afforded by the baffle justifies its initial cost, maintenance, and possible alterations to rainfall and solar radiation.

The results (Figure 3c) using the nozzle top were superior to all other designs tested with respect to concentration uniformity. Dilution of the gas mixture became a serious problem only toward the downwind portion of the chamber. Concentration values in the upwind third of the chamber were nearly equal to the concentration of ethylene in the gas mixture inlet. The main disadvantages to this design are the reduction of rain and solar radiation entering the chamber. Further investigations should center on the formulation of design modifications (e.g., nozzle top, air inlet, and baffles) that would reduce rainfall and solar radiation bias.

An experiment was also run with the wind tunnel turned off while the gas mixture continued to enter the model chamber. With plants both in and out of the chamber (Figure 1a), very low gas concentrations were observed in the region near the blower box, particularly near the top of the chamber. These low concentrations were the result of an enhanced entrainment of outside air due to an uneven distribution of flow through the holes in the chamber sidewalls. The gas mixture velocity was greater through the holes near the inlet tube than it was through the other holes. Flow visualization studies using titanium tetrachloride showed a strong inflow of outside air at that point (above the gas mixture inlet) of the model. This effect was more intense when plants were in the chamber. As the gas mixture left the inlet tube and entered the chamber via the inlet holes, it was channeled between the two rows of plants (Figure 2). These plant rows acted as baffles, thus preventing rapid mixing with gas mixture streams entering the chamber from holes along the sides. Tests will be required to determine if such events occur in the field.

Virtually no dilution was observed with the nozzle top chamber (Figure 1c). Three factors are important here. First, the nozzle effect of this chamber causes a higher chamber-top velocity than is observed in the other chamber types. In addition, exterior geometry and increased distance to the nozzle exit also contribute to the observed differences.

A comparison of wind tunnel results with those obtained in the field by Heagle, *et al.*[2] indicated substantial differences, which aside from the obvious wind tunnel/field condition dissimilarities, could have arisen from variations in such factors as crop type and arrangement, sensor number and location, and trace gas used. Before wind tunnel data can be used to assess the usefulness of open top field chambers or to aid in future design changes, work needs to be done comparing wind tunnel data with those obtained in the field. At present, it would be premature to use our current wind tunnel data for a full evaluation of open top field chamber designs now in use.

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References

1. A. S. Heagle, D. E. Body, and W. W. Heck, "An open-top field chamber to assess the impact of air pollution on plants," *J. Environ. Quality* 2: 365 (1973).
2. A. S. Heagle, R. B. Philbeck, H. H. Rogers, and M. B. Letchworth, "Dispensing and monitoring ozone in open-top field chambers for plant-effects studies," *Phytopathology* 69: 15 (1979).
3. G. Kats, C. R. Thompson, and W. C. Kuby, "Improved ventilation of open top greenhouses," *JAPCA* 26: 1089 (1976).
4. R. H. Mandl, L. H. Weinstein, D. C. McCune, and M. Keveny, "A cylindrical open top chamber for the exposure of plants to air pollutants in the field," *J. Environ. Quality* 2: 371 (1973).
5. W. H. Snyder, "Guidelines for Fluid Modeling of Atmospheric Diffusion," U. S. Environmental Protection Agency, EPA-450/4-79-016, 1979.
6. W. H. Snyder, "The EPA Meteorological Wind Tunnel: Its Design, Construction, and Operating Characteristics," U. S. Environmental Protection Agency, EPA-600/4-79-051, 1979.

7. R. J. Kohut, S. V. Krupa, and R. Russo, "An Open-Top Field Chamber Study to Evaluate the Effects of Air Pollutants on Soybean Yields," *Fourth Joint Conference on Remote Sensing of Environmental Pollutants, Proceedings*, American Chemical Society, New Orleans, LA 1977. pp. 123–125.
8. S. V. Krupa, Personal communication. Plant Pathology Dept., University of Minnesota, St. Paul, 1979.
9. S. D. Nystrom, D. C. Johnson, and S. V. Krupa, "Microcomputer Controlled System for Exposure of Vegetation to Air Pollutants in Open-Top Field Fumigation Chambers," *Proceedings of the American Phytopathological Society*, Abst. 1978. p. 112.
10. A. A. Townsend, *Structure of Turbulent Shear Flow*, Cambridge University Press 1956.

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