Determination of Air Movement in Stored Grain as a Factor in Dynamic Dispersion and Distribution Patterns of Gaseous Pesticides (Fumigants)[1]

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Recent research (BERCK, 1973; 1974) on the application of Dowfume EB-5, a commercial fumigant mixture containing ethylene dichloride, ethylene dibromide and carbon tetrachloride to 1,000 bushels of infested wheat yielded greater variation in residues of the components than was obtained in small-scale, laboratory experiments that preceded the field application. Unlike laboratory experiments under isothermal conditions, the field experiment was subject to local changes in outside environment for a 7-week period. Thus, temperature differences as great as 60°F (33°C) were found on a sunny day, wherein the temperature at the top surface of the bin might reach 120°F (49°C) while the temperature at the ground level might be 60°F (16°C). Such a temperature gradient would readily cause pressure differences within the internal weather system (microclimate) of the grain bin. This in turn would affect the airflow rate in much the same way as air movement is initiated and maintained through the interaction of sufficiently wide temperature gradients in localized areas of Planet Earth. The velocity of air movement in Nature may thus range from 1 to 100 or more miles per hour (mph) under "open", natural conditions. Among the air velocity factors of the macro environment are height above ground level, and local as well as regional geography.

It was considered useful to attempt to determine airflow and airflow patterns in grain for better understanding of the considerable variation in fumigant residues. The latter were influenced by location of the sample, by residence or contact time of the fumigant gas, and by fumigant gas concentrations (BERCK, 1973; 1974). An additional objective was to determine air speed and direction of flow as factors in conveying normal respiratory metabolites such as carbon dioxide and water vapor within a grain mass from point A to point B.

Aspects of the Problem. Air is a compressible fluid (see aerodynamics). The speed and direction of airflow are affected by a variety of factors, e.g., the geometry of a room, the shape of a vessel or chamber, and by temperature and pressure differences. The composition of air is highly variable and will depend on the local environment. Thus, in ambient air, over 200 compounds are

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Bulletin of Environmental Contamination & Toxicology, Vol. 13, No. 5

present, as may be determined by capillary gas chromatography. The content of water vapor and carbon dioxide, particularly in the grain microclimate, are important to efficiency of fumigation and vary considerably.

The velocity of motion of the air outside or above a grain storage bin is readily determined by hot-wire or sonic anemometers. However, they cannot be used to measure air speeds that are less than 0.01 (10^{-2}) mph, nor can they be used inside a grain bin to measure the interstitial air speed. Our initial estimate of air speed in grain was 10^{-3} mph. Each bushel of grain normally has over 1 million kernels. Thus, 1,000 bu of grain (30 tons, 27.3 metric tons, with a volume of 1250 ft. or 35.5 m^3) would contain well over 1 billion (10^9) kernels, each offering flow resistance to the entrapped interstitial air.

In the initial plan, the use of labelled gases, and sorption factors that should be assessed beforehand, were considered. For the latter purpose, unlabelled carbon dioxide and carbon tetrachloride were each applied at 50 ppm levels to a grain column 6 feet in height, and were found to be unsatisfactory because of their considerable sorption by the wheat. In addition, estimation by gas chromatography of their residual amounts in air was not sufficiently reproducible or sensitive for our experimental requirements. Furthermore, for the express purpose of serving as a micrometeorological marker, it was felt that the initial concentration of applied marking compound should be small (e.g., 10 ppm) to avoid the "swamping" effect that higher concentrations might have (BERCK, 1968; BERCK and GUNTHER, 1970).

EXPERIMENTAL

Sulfur hexafluoride (SF_6), used by SALTZMAN *et al.* (1966) among other halogenated compounds, was confirmed as an ultra-sensitive micrometeorological tracer that could be measured by GC with an electron capture (EC) detector. When 250 g dry grain (12.5 and 11.5% moisture content, respectively) was exposed for 10 days at 23°C to air in a closed 1-l. flask containing 10 ppm SF_6 in air, no sorption was found, as shown by constant levels of SF_6 concentration in the headspace atmosphere. We were able to determine amounts as low as 0.1 picolitre (10^{-13} litre, or 100 femtolitres) of SF_6 in air. In actual practice, we injected 250-µl aliquots of air samples into our Fisher-Victoreen GC apparatus and measured the SF_6 concentrations at regular time intervals. For most of our requirements, it was sufficient to identify the presence of trace amounts of SF_6 in the air as an indicator that the air had moved from point A to point B.

With this ultrasensitive tool we are currently measuring air-speeds as low as 0.5 x 10^{-4} mph (equivalent to 3 inches per hour), which is well below the normal breathing rates of humans, and very much less than the lowest air speed measured to date by others.

Figure 1 shows a standard curve for SF_6 in the range 1 - 35 picolitres.

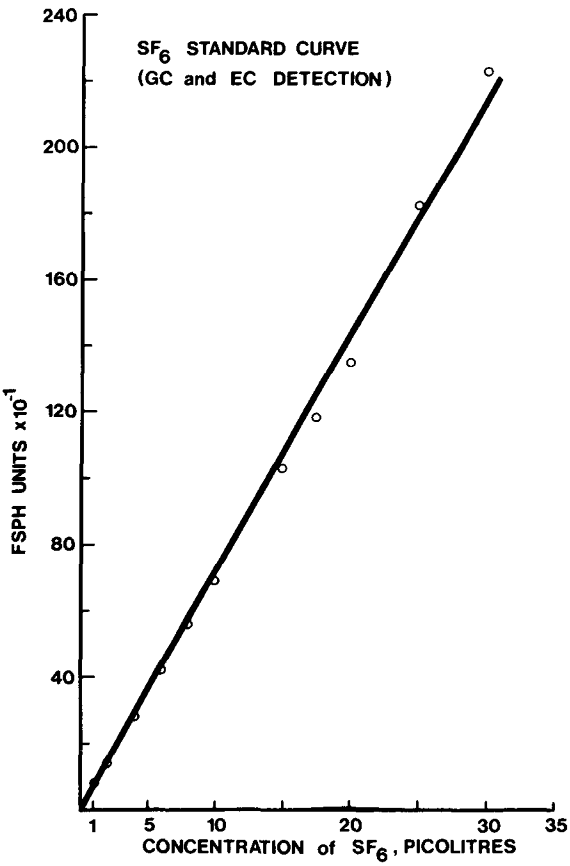

Figure 1. Standard curve, range 1-35 picolitres SF in air, determined by gas chromatography with a Ni^{63} EC detector.

In our initial experiments, we used a sealed 6 ft x 4-inch diam. PVC pipe with sampling stations located at 12-inch intervals. A SF_6 standard (15 cc of 10 ppm, v/v dilution) was injected first at the top and later, in a separate experiment, at the bottom. Air samples were then taken from each of the 6 sampling stations at periodic intervals. The rate of upward, downward and lateral travel of the marker gas (SF_6) was thus determined in the column in both a vertical and horizontal axis at different temperatures.

Steel columns of 12-inch (0.3 m) diam. and 7½ ft and 16 ft (2.3 and 4.9 m) in height, respectively, were used thereafter. The columns were filled with wheat, barley, oats, flax, rapeseed, mustard seed or peas, and both downward and upward air movement were determined. We are presently testing 5-ft and 30-inch diam. steel columns, each holding 20 bushels. After the SF_6 was injected in 10-ppm amounts to the top or bottom of the steel column, 3-cc air samples were taken by syringe from 9 separate points at each level, each level being located at 1-foot intervals from the top or bottom. A total of 45 points were thus sampled in each 5-ft bin at regular time periods.

Figure 2 shows the sampling pattern used, in which ½-inch o.d.

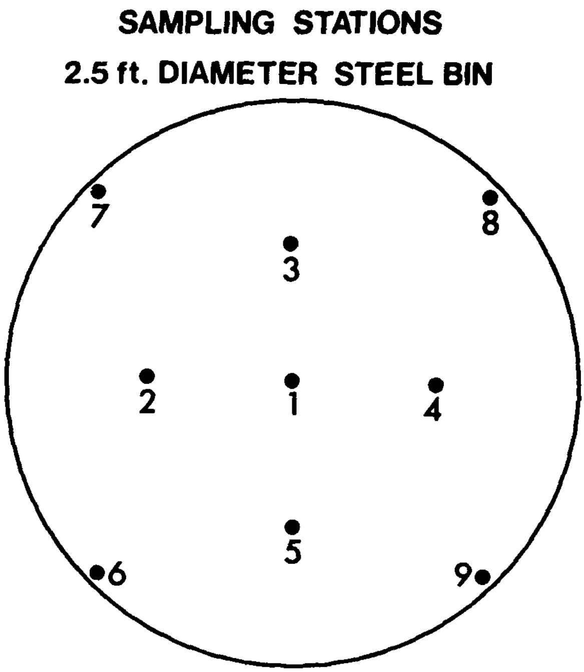

Figure 2. Location of 9 sampling stations in a 2½-ft diam. steel bin. Five 9-station groups were located at 12-in intervals along a vertical (height) axis.

polyethylene tubes leading to the perimeter and upper levels of the bin were place in position beforehand. Rubber septums were fitted to the end of each tube to permit sampling by syringe. In each case, about 4 cc of air were first drawn from each sampling point and discarded to flush residual air from the tubing. A 3-cc air sample was taken immediately thereafter in a syringe capped with a rubber septum. Aliquots of 250 µl were then injected into the Fisher-Victoreen gas chromatograph fitted with a Ni^{63} EC detector. Using a Porapak QS column, the retention time of SF_6 in air at 125°C was 1 minute, 26 seconds.

Results and Discussion

The program is still continuing under laboratory (controlled) conditions to enable us to establish the parameters and obtain the experience needed to measure interstitial airflow in large bulks of grain stored under terminal, country elevator or farm conditions. In bins under commercial and field environments conditions would not be isothermal, such as we have used to date. Present indications are that non-linear behavior would be found under field conditions. In the meantime, when grain temperatures were isothermal, the upward and downward movement respectively were virtually identical. If, however, the bottom temperature was cooler, the downward speed was greater than the upward speed.

The air speeds of the interstitial air that we ascertained to date by this new method ranged from 0.5×10^{-4} mph (3 inches per hour), and were influenced by the nature of the stored product, including the size and geometrical shape of the kernels, and the storage temperature.

Figure 3 shows typical results obtained with SF_6-tagged air

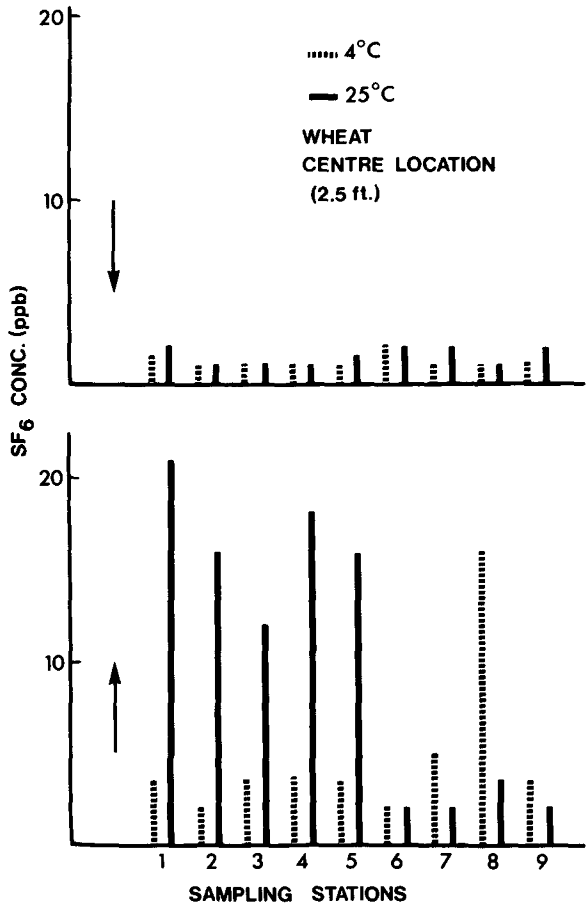

Figure 3. Downward and upward air movement, using SF_6 as a marker, at 9 centre locations (see Figure 2) in a 5-ft x 2½-ft diam. steel bin, at 4^{o} and 25^{o}C, respectively.

moving in downward and upward directions in wheat, respectively, as shown in samples taken at the 9 sampling stations located in the center (2½ ft height) of a 5-ft x 30 in diam. steel bin. Differences in terms of ppb (v/v) concentrations are shown at 4° and 23° C, respectively.

While our sampling priorities were geared to detect the presence of SF_6 to signal exactly when the tagged air had arrived at the sampling point, we also determined the ppb concentrations of SF_6 at the same time, as is shown in Figure 3. However, the latter are less important for unassisted air velocity determination by the foregoing method, since the ppb levels at any point would be time-dependent in a sealed system.

Applications. We are interested in the peripheral movement in our current 2½-ft diam. experimental bins and found slight differences at the periphery as compared to the central core. We have also applied the method, in collaboration with Prof. H. M. Gawley, Mechanical Engineering Dept., University of Manitoba, to estimate the amount of air that can be reintroduced by a high-speed "air wheel" used for air-conditioning of a hospital ward. The air wheel in this instance had an estimated wind speed of 50 mph and we ascertained that 0.5 to 2% of the volume of air removed was reintroduced, depending on the particular settings of the air wheel.

With the aid of this new capability of determining "super-slow" air speeds down to at least 10^{-5} mph (0.6 inches or 15 mm per hour), it may be possible to elucidate the movement patterns of water vapor in different microclimates, and also of volatile substances such as DDVP, Hg vapor, Pb vapor, aerosol vapors, and other components of the complex mixture of gases, vapors and micronized dusts that we designate as "air". We also see possibilities of measuring the rate of translocation of obnoxious odors such as are generated by feedlots and large-scale livestock production and that emanate from the mountains of manure that evolve.

In addition, there are possibilities of measuring air movement velocities in granulated or powdered materials that are stored, such as sugar, flour, cornstarch, cement, sand, granulated coal, etc. The packing density, which varies considerably, would be a factor. Of basic importance, however, is the requirement that the SF_6 used as a micrometeorological tracer gas should not be sorbed by or combined with the substrate or product.

Asymmetry in heat loss as a function of differential airflows, and the "chimney effect" that in a grain bin would tend to push up and oppose the downward migration of fumigant mixtures applied to the surface of a bin are additional areas of possible investigation.

Summary. The new research reported herein was motivated by variations in distribution-persistence patterns of fumigant residues (BERCK, 1974). The current developmental program is still underway. In the meantime, measurement of picoliter amounts of SF_6 in air by GC equipped with a Ni^{63} EC detector has been proven useful over an airflow range of 10^{-4}

to 50 mph, representing a factor of 500,000 in differences in air velocity. Diverse applications have been outlined herein.

This is the first case on record where measurement of unassisted airflow in the interstitial air of stored grain has been successfully executed, and which enabled determination of airflow speeds in the range 0.5 to 7.5 x 10^{-4} mph (=3 to 45 inches per hour).

Acknowledgement

The author acknowledges the following Manitoba Environmental Research Committee (MERC) research assistants who participated in the execution of this project: Subhash Chandra, Phil Geisel, Mike Leitch and Motilal Patram. These and other assistants worked on MERC environmental projects through two research grants provided by the Environmental Management Division and the Manitoba Department of Mines, Resources, and Environmental Management. The author also acknowledges the assistance of the Manitoba Pool Elevators, Northern Sales Ltd., and Kenmore Industries Ltd., all located in the Winnipeg area, in providing the short-term loan of considerable quantities of cereal grains used in this investigation.

The information in this report was presented as paper 531 to Section II B, Third International Congress of Pesticide Chemistry, Helsinki, July 2 - 9, 1974.

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