STRUCTURAL FUMIGATION MODELING FOR PREDICTION OF GAS MOVEMENT AND HALF-LOSS TIME

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The phase-out of methyl bromide as the major fumigant for use in structural fumigation has warranted the industry to seek alternative pest control measures. A variety of alternatives such as heat treatment, ECO_2Fume® (98% CO_2 with 2% phosphine), Profume® (Sulfuryl Fluoride), and a combination of heat treatment and ECO_2Fume® have been proven effective. However, unlike methyl bromide most of the alternatives require higher concentrations and longer periods of exposure. This means that the key for successful adoption of these alternative measures lies in the efficiency of their application during fumigation. Because it is not practical to build and seal a structure completely gastight, the fumigation process can only be better optimized and controlled once we have a better understanding of the physics and dynamics of gas movement in the fumigated space and of the effects of various factors such as properties of the fumigant, characteristics of the structure, and environmental conditions on the fumigation process.

In September 2004, Purdue University received a 3-year grant from the USDA-CSREES Methyl Bromide Transitions Program for a project entitled *Fumigation Modeling, Monitoring and Control for Precision Fumigation of Flour Mills and Food Processing Structures*. During the first year of this project, computer simulations of the structural fumigation process in a portion of a flour mill have been conducted and data has been collected during a full-scale flour mill fumigation to validate our modeling effort. For the purpose of this conference presentation, our objective was to develop a methodology for using Fluent®, a commercial Computational Fluid Dynamics (CFD) solver, to capture the effect of natural wind velocity on the fumigant leakage rate, which is expressed in terms of half-loss time (HLT) values.

The structure modeled in this study was a commercial flour mill having six floors with an approximate total volume of one million cubic feet. Based on a previous fumigation data, the flour mill had an estimated HLT of 10 hours. The aim was to obtain CFD models that were able to confirm this HLT value. Two flow models, one for the flow outside the structure and one for the flow inside the structure, were developed. The information of the pressure profile on the external wall created in the external flow model was used for constructing the boundary conditions (BC) for the internal flow model. The external flow simulation was performed as a steady-state flow. A constant velocity profile and a fixed static pressure value were specified at the inlet and the outlet BCs, respectively. Based on the weather data from a near-by metrological station, it was assumed that the wind velocity was 9 miles per hour from the north direction.

The internal flow simulation was considered an unsteady flow because the fumigant concentration changed over time. Instead of modeling the entire building and spending excessive computational time, it was decided to reduce the flow domain and minimize the computational time by considering only the flow on the fourth floor (Figure 1). An assumption that there was no flow interaction between the fourth floor and the other floors was made. The dimensions of the simulation domain were 18 ft height, 89 ft width, and 117 ft length. The domain contained porous packed beds representing four rows of flour sifters on the floor, a stairwell, an elevator shaft, grain tempering tanks, and building columns. Geometrically, a row of sifters was represented by a rectangular box. A flow resistance value was specified such that the pressure drop created by these porous packed beds resembled the pressure drop created by the sifters. It was assumed that the flow through all the cracks on a wall can equivalently be represented by the flow through an effective leakage zone ELZ. An ELZ is a porous zone with an assumed cross-sectional area and an assumed resistance factor. An ELZ was placed on each of the north, east, and west walls. The south side of the flour mill building was connected to the packaging area and thus it was assumed that there was no leak through the south wall. Thirty one monitoring locations were laid out throughout the flow domain. At each simulation time step (10 seconds), fumigant concentrations in these monitoring zones were collected.

The external flow simulation indicated that higher pressures acted on the windward walls and lower pressures acted on the leeward walls. Therefore, it stands to reason that the majority of fresh air infiltrating the sealed flour mill building will be through the windward (north) wall and the fluid inside the building will escape through the east and west walls. The area average total pressure on the north wall was approximately 3.48 Pascal, which was assigned to the pressure inlet boundary. The values of the area average static pressures assigned to the pressure outlet boundaries on the east and west walls were 0.43 and -1.87 Pascal, respectively. Once the values for the pressure inlet and outlet boundaries were obtained, several internal flow simulations were conducted with various resistance values for ELZ to determine a resistance value that would give a HLT of 10 hours. In the simulations, the fumigant was initially released such that the initial concentration was about 29 oz/Mcf and the building was fumigated for 24 hours. The combination of 29 oz/Mcf initial concentration, 24 hours exposure time, and 10 hours HLT resulted in an achieved C x t product of approximately 340 oz-hr/Mcf. This C x t product value was the target dosage used in the fumigation from which the concentration data referred to in this study was collected.

Figure 2a is a plot of the concentrations at the 31 monitoring points. Areas in which the concentration was not able to reach 29 oz/Mcf were in the stairwell and near the ELZ with the pressure inlet boundary. The concentration in the stairwell increased slightly slower than the other locations. This was because the fumigant had to enter the stairwell through a door which created a slight pressure drop. The concentration at the monitoring location in front of the

ELZ with the pressure inlet boundary was almost not detected. Once the initial concentration was established and uniformly distributed, the concentrations started to decay because of the leakage. It was found that the HLT at each monitoring location was approximately 10 hours. Figure 2b is a plot of the C x t products corresponding to the concentration curves in Figure 2a. The C x t products achieved in most areas were close to the target C x t, 340 oz-hr/Mcf, which indicated a successful fumigation.

This study showed that modeling the process of structural fumigation using CFD is practical. A Fluent®-based gas movement model will enable the simulation of various “what if” scenarios and possible fumigation strategies such that fumigation applications can be custom-applied based on the prevailing site-specific conditions. It will be used to predict the fumigant gas concentration over time and the effect of various environmental disturbances during the fumigation process for which counter measures could be devised to mitigate against these disturbances.

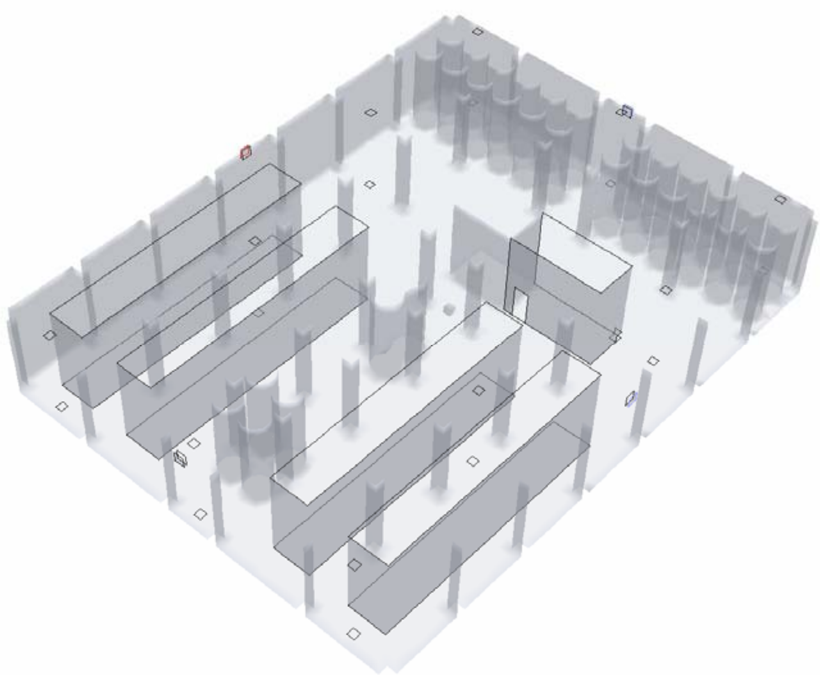
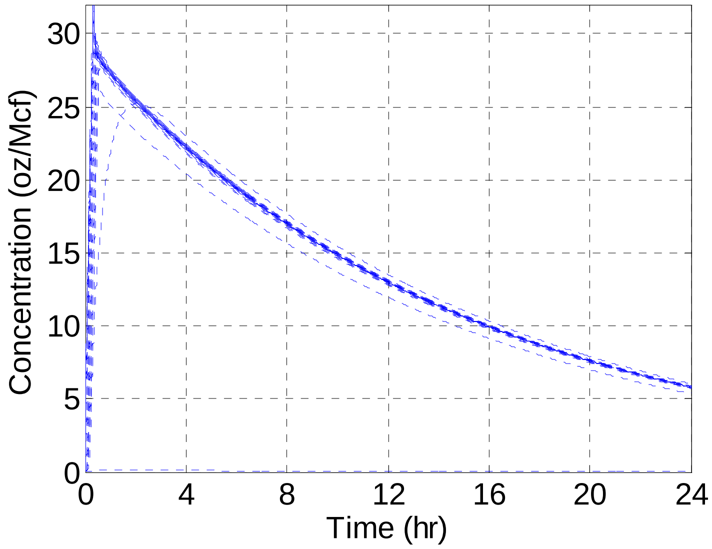
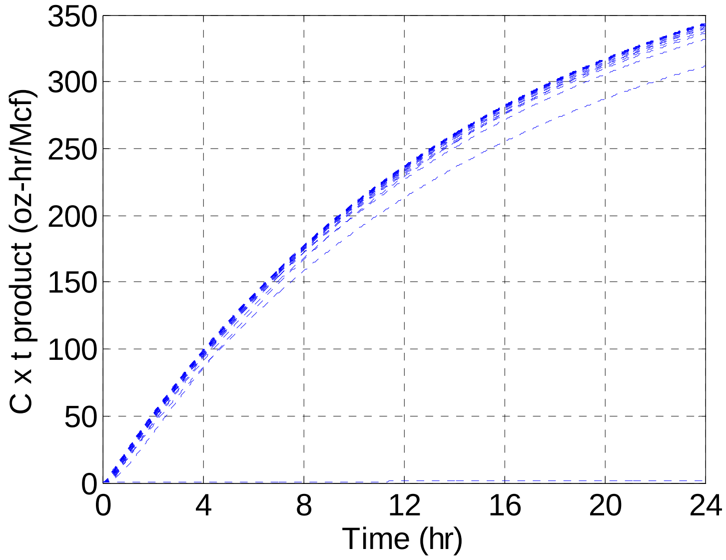


Figure 1. Geometry setup of the internal flow model which included only the fourth floor of the flour mill building.



(a)



(b)

Figure 2. (a) Plot of concentration changes at the 31 monitoring points. (b) Plot of the C x t products corresponding to the concentration curves in (a).