

APPLICATION ASPECTS OF IMPROVING STRUCTURAL FUMIGATION

Watcharapol Chayaprasert¹, Dirk E. Maier*¹, Klein E. Ileleji¹, Jayathi Y. Murthy², and Linda J. Mason

¹Agricultural and Biological Engineering Department, ²Mechanical Engineering Department, ³Department of Entomology, Purdue University, West Lafayette, IN 47907

In August 2004, researchers in the departments of Agricultural and Biological Engineering, Mechanical Engineering, and Entomology at Purdue University with funding from the USDA-CSREES Methyl Bromide Transition Program and in collaboration with industry partners initiated a research project with the aim to develop a comprehensive analysis tool, and an automatic monitoring and decision support system for structural fumigation. Since the project started, we have conducted several theoretical analyses, computer simulations and fumigation experiments. This paper summarizes our findings and explores several possibilities and technologies to improve the structural fumigation process.

Since the beginning of the project, eight fumigation monitoring experiments have been conducted as part of regular fumigations of three commercial flour mills. In addition to fumigant concentrations, the environmental conditions both inside and outside of the fumigated facilities were continuously monitored during the experiments. While sealing appeared to prevent major heat loss from the fumigated structure, the pressure data indicated that the hydrostatic pressure in the structure was coupled to and dominated by the barometric pressure of the environment and that sealing did not create sufficient airtightness to cause a pressure build-up inside the structure due to the introduction of the fumigant. In addition, operation of the circulation fans did not contribute to fumigant leakage because it had no effect on the hydrostatic pressure inside the structure. However, the circulation fans aided in reducing the time to achieve uniform fumigant concentrations on each floor and between floors of the structure.

We performed a theoretical analysis to quantify the improvement in concentration \times time (Ct) product over a range of half-loss time (HLT) values. It was found that regardless of the fumigation magnitude by improving sealing quality such that HLT is increased from 10 to 12, 14, 17 and 20 hours, Ct product of a 24 hour fumigation could potentially be increased by 10, 20, 30 and 40%, respectively, from the 10 hour baseline. Significant increases in Ct product due to improved HLT were also practically observed in our fumigation experimental results. However, as HLT increases above 20 hours, the percentage gain in Ct product decreases. This implies that oversealing might not substantially benefit the gain in Ct product. The effect of fumigant gas sensor accuracy was also illustrated by performing a theoretical analysis. The analysis showed that the accuracy of fumigant gas sensors determines the potential amount of fumigant over- and under-dose. Effectively, the potential error range of Ct product calculations is the same as the measurement error range of a fumigant concentration sensor. For example, if a fumigant concentration sensor has an accuracy of $\pm 10\%$, at any point in time the Ct

product from measurements by this sensor would fall within a $\pm 10\%$ error band of the true Ct product, regardless of the values of the initial concentration and HLT. And for this particular example, in the worst case scenario the fumigant must be over-introduced by 11% in order to ensure the target Ct product.

Two CFD models have been developed and validated based on two reference flour mills. Given weather conditions, the models can be used to predict fumigation characteristics such as fumigant movement paths, concentration distributions, and leakage rate. The effects of fumigation variables such as wind speed and direction, capacity and placement of circulation fans, and fumigant release time on the efficacy of the fumigation process can also be evaluated. One of the models was used to illustrate the effects of different weather conditions on fumigation performance under the same fumigation practices (e.g., sealing quality, circulation fan placement, amount of fumigant etc.) This study is discussed in more details in a second presentation by the same authors entitled “SIMULATING THE EFFECT OF WEATHER CONDITIONS ON STRUCTURAL FUMIGATION” in this conference. In a third presentation entitled “INVESTIGATION OF GAS DISTRIBUTION DUE TO CIRCULATION FANS IN STRUCTURAL FUMIGATION”, the two models were used to investigate the effectiveness of different configuration of circulation fan placement on fumigant distribution.

The fumigation monitoring and control system is another essential component for the success of a fumigation. In current fumigation practices, fumigated space temperature is not monitored during fumigation. However, it is commonly known that for any fumigant the Ct product required to kill a particular insect species varies as a function of the temperature of the fumigated space. In one of our fumigation experiment, we found that the temperature inside a sealed structure can decrease by as much as 9 °C. This finding emphasizes the importance of temperature monitoring. In our simulation study of the effect of weather conditions, it was shown that given the same sealing quality year-to-year variations in weather conditions could create significant differences in fumigant leakage rate (≈ 10 hour difference in HLT). Substantial variations in HLT of a structure (≈ 10 hour difference) between fumigations were also observed in our fumigation experiments. These findings indicated that monitoring of environmental condition of both inside and outside of the fumigated structure should be incorporated as a best management practice in every fumigation management plan. Currently, fumigators monitor fumigant concentrations by taking measurements every 2 – 4 hours. This practice can easily lead to inaccurate HLT and Ct product estimations. Based on our experimental results, while the actual HLT of a structure was 8 hours, the estimated HLT could be as much as 30 hours if gas concentration readings were taken 4 hours apart.

Based on our experience and findings during the course of this research project, in order to reduce the labor workload and improve the performance of the structural fumigation process we envision that:

- Fumigation monitoring should be continuously and automatically performed
- Gas concentrations should be measured via wireless sensors that can be placed at multiple locations in the fumigated structure

- Environmental conditions both inside (e.g., temp/RH) and outside (e.g., temp/RH and wind speed/direction) should also be monitored
- Recommendations for fumigant application based on a deterministic control strategy should be provided to the fumigator
- Fumigators should be able to access the status of key monitored parameters and recommendations for fumigant application through a local computer screen plus the internet and/or cell phone networks

These improvements will lead to cost and product stewardship program benefits. Continuous monitoring of gas concentration and environmental condition will allow more accurate HLT and Ct product calculations and better fumigation records for future fumigation planning. A deterministic control strategy will eliminate guesswork out of fumigant dosing. Wireless gas sensors will cut down the time needed for fumigation preparation and cleanup which leads to reduced production down time. With the automated system and remote access feature, fumigators will be able to manage multiple fumigations virtually from any locations.

Due to several limitations, all of the improvements mentioned in the previous paragraph could not be achieved at the present time. However, using off-the-shelf parts we have built a prototype of an automatic fumigation monitoring and decision support system. The system is capable of automatically measuring fumigation concentrations at several locations and providing recommendations for fumigant dosing. However, instead of internally placed wireless sensors the system still utilizes the tube-and-pump method to draw gas samples from inside the fumigated structure and pass the sample through a gas sensor located at the outside. Each monitoring tube is connected to a solenoid valve (Neptune Research Inc., West Caldwell, NJ). The system consists of 15 valves and thus can accommodate up to 15 monitoring tubes. The valves are automatically controlled. The fumigant concentration sensor is the Spectros Instruments Single Point Monitor from Spectros Instruments Inc., Hopedale, MA. A generic fumigation decision support program is written in LabVIEW (National Instruments Corporation, Austin, TX). Currently, the program uses the same HLT/Ct calculation algorithm as the one used in the fumigation management software, Fumiguide™, developed by Dow AgroSciences, Indianapolis, IN, for sulfuryl fluoride gas fumigant (ProFume®). However, the program can be modified to suit any fumigant if the required Ct product information of the fumigant is available. The environmental condition monitoring and remote access features have not yet been implemented at this time. This monitoring and decision support system has been tested in four of our fumigation experiments. Overall, the system performed satisfactorily.