SIMULATING THE EFFECT OF WEATHER CONDITIONS ON STRUCTURAL FUMIGATION

Watcharapol Chayaprasert[1], Dirk E. Maier*[1], Klein E. Ileleji[1], and Jayathi Y. Murthy[2]
[1]Agricultural and Biological Engineering Department, [2]Mechanical Engineering Department, Purdue University, West Lafayette, IN 47907

Estimating the half-loss time (HLT) is one of the most difficult tasks for fumigators. Fumigators assume no variation in weather conditions and rely on concentration readings from past fumigations when estimating the HLT value for a particular structure. Most of the time, fumigant overdosing is the approach taken to reduce the chance of a fumigation failure due to inaccurate HLT estimation. This results in excessive fumigant use and unnecessarily increases cost. Due to the substantial fumigation-to-fumigation variation, producing experimental replicates, in which certain parameters of interest are varied and all the other parameters are kept unchanged, is costly and almost impossible to implement. The primary objective of this study was to utilize the validated CFD models developed by Chayaprasert et al. (2006b) to evaluate the effect of multi-year weather conditions on the gas leakage rate (i.e., HLT) and the concentration×time (Ct) product during structural fumigation in a reference flour mill. Eleven fumigation simulations were performed using historical weather data of the same time period between 1996 and 2006.

It was assumed that for each year's simulation (1996 – 2006) the fumigation started at 12:00pm on the 4th of July and lasted 24 hours. Hourly average historical weather data collected at a weather station closest to the location of the reference flour mill was used. The weather conditions were assumed constant during each fumigation hour. The data included temperature, relative humidity (RH), barometric pressure, and wind speed and direction. For all eleven simulations, the fumigation practices (including fumigation preparations) were assumed to be the same as for those described by Chayaprasert et al. (2006a) except that in this study circulation fans were continuously operating during the entire fumigation period. The average temperature in the mill was assumed to be 30 °C. The fumigant was sulfuryl fluoride (ProFume®). One fumigant introduction site was located around the middle area of each floor. At each introduction site, a circulation fan (2.71 m^3/s) was placed. A total of 226.8 kg of sulfuryl fluoride was released into each floor of the mill. The first half (113.4 kg) was released at the beginning of the fumigation and the second half was released approximately two hours later. The fumigant concentrations were monitored at 18 locations distributed throughout the mill.

In many cases, the simulations showed significant differences in the leakage rate. The lowest and highest leakage rates were found in 1996 and 2004, respectively. The initial concentration for 1996 was approximately 54 g/m^3 which was 9 g/m^3 higher than that for 2004. The differences in the initial concentrations indicated different gas leakage rates during the gas injection period. The HLTs for 1996 and 2004 were 23.3 and 10.7 hours, respectively. The higher HLT resulted in a Ct product of 840 $g\text{-}hr/m^3$ while the lower HLT yielded a Ct product of 476 $g\text{-}hr/m^3$. This showed that if the HLT of the 2004 fumigation was estimated based on the concentration readings from the 1996 fumigation, the 2004 fumigation could potentially be a failure due to the lack of sufficient gas injection.

In general, the higher wind speeds and larger temperature differences between the inside and outside of the fumigated structure created greater pressure differences across the structure's envelope, which lead to the higher leakage rates. It should be noted that the pressure difference profile is a function of the combination of wind speed, wind direction and temperature difference. As an example, while the average wind speed, mode wind direction and average ambient temperature in 2000 and 2002 were 2.1 m/s, 0 degree and 24.4 °C, and 3.2 m/s, 45 degrees and 29.1 °C, respectively, the combination of the parameters for both years resulted in approximately the same HLT (20 hours) and Ct product (750 g-hr/m^3).

Surrounding structures located nearby the fumigated reference flour mill created a barrier that reduced wind speed from certain directions before the wind impinged on the fumigated structure's walls. Also, the shape of the fumigated structure may form smaller wind impact areas from certain angles. In addition, cracks and crevasses may be clustered more in certain areas on the structure's wall than others. For the reference flour mill in this study, the north and south walls have less cross-sectional areas than the east and west walls and surrounding structures (e.g., grain bins and silos) are located only to the north of the flour mill. Therefore, wind from the north direction (0 degree) did not create as much leakage as did wind from the other directions. For example, while in 1998 the average wind speed was 4.4 m/s which was higher than the average wind speed in 2001 (3.5 m/s) and the ambient temperatures in the two years were approximately the same, the HLT and Ct product in 1998 (18.2 hours and 757 g-hr/m^3) were both higher than those values in 2001 (15.5 hours and 696 g-hr/m^3). The higher wind speed in 1998 essentially created less leakage than the lower wind speed in 2001 because in 1998 the dominant wind direction was from the north (0 degree) while in 2001 wind traveled mostly from the west (270 degrees).

Although the simulated fumigations in this study were performed with the same temporary structural sealing quality for the same time period of the 11 years, the year-to-year variations in the weather conditions caused differences in initial concentrations, HLTs and Ct products. The average values and standard deviations (in parentheses) of the initial concentrations, HLTs and Ct products of all years were 50.5 (2.7) g/m^3, 16.2 (3.7) hours and 671 (101) g-hr/m^3. In extreme cases, the initial concentration was almost 20% different (from 54.3 to 44.6 g/m^3) and the HLT was more than 100% different (from 10.7 to 23.3 hours), yielding a difference in the achieved Ct products by more than 70% (from 476 to 840 g-hr/m^3). This means that for a given structure even though the fumigator could maintain the same sealing quality for every fumigation, the difference between the HLT predicted based on past fumigation data and the actual HLT observed during the current fumigation could be substantial. The fumigator would either overdose in the case of underpredicted HLT or have to intermittently release additional fumigant in the case of overpredicted HLT, resulting in a non-optimized fumigation process. As a result, past fumigation data should not be the primary means for evaluating the effectiveness of sealing. The effectiveness of temporary structural sealing should be measured under controllable conditions. One standardized method is the pressurization test, also known as the blower door test. With this testing method, the tested structure is pressurized at different constant pressure levels using a specially calibrated fan(s). At each pressure level, the air flow rate that passes through the pressurization fan is measured. The pressure-flow rate measurements are then plotted to form the leakage characteristic curve which can be used to calculate the structure's effective air leakage area. The effective air leakage area is a quantifiable index used to compare air-tightness (i.e., the effectiveness of sealing) between any structures. In addition, a calculation procedure for air leakage rates due to weather conditions has also been suggested, in which the effective air leakage area is incorporated. These pressurization tests and air leakage rate calculation procedures can be directly applied to the prediction of HLT, given weather forecasts for the planned fumigation period. Therefore, HLT prediction could be substantially improved and increase the fumigation performance.

Reference:

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