WIRELESS MONITORING OF THE INDOOR AIR ENVIRONMENT IN A WINERY DURING HARVEST

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SUMMARY

The purpose of this study was to establish a wireless monitoring system for air environment in the fermentation hall of a winery during harvest. Sensor boards with wireless communication were developed for the measurement of carbon dioxide, temperature, humidity, volatile organic carbon and particle counts during the 2014 harvest in the LEED Platinum Teaching and Research Winery at UC Davis. The study confirmed the effectiveness of the vapour capture system of the building design to keep the ambient carbon dioxide levels well below exposure limits and that more studies are needed to understand the source and fate of the volatile carbon compounds and particles and the role of people and equipment movement on the particle patterns.

INTRODUCTION

Wineries, breweries and many food facilities differ from standard office and occupied buildings in that they are unconditioned spaces with significant movement of materials during normal operation. The seasonal nature of the grape harvest and the higher levels of fermentable sugars distinguish wineries from breweries in terms of the levels of carbon dioxide and ethanol vapour released during fermentation. In wineries, grapes are received and fermentations are conducted only during an 8 to 10 week period. During this period outside doors will be open for activities such as grape bin delivery, crushing and pressing with daily cleaning and washing of most process equipment and periodic cleaning of a fermentation tank when fermentation is completed.

The evolution of carbon dioxide and ethanol vapour as emissions from the ethanol fermentation pose significant worker exposure issues and there is essentially no information about the ambient levels of these components in winery buildings during harvest. Carbon dioxide in workplace air has an OSHA permissible exposure level (PEL) of 5000 ppm (Crowl and Louvar, 1990) and when released in a concentrated form such as from a wine fermentation, it is denser that air. Ethanol vapor which is a natural part of the fermentation emission has a PEL of 1000 ppm with most federal and state agencies, and this seems to have been established only recently in 2009 (OSHA, 2014). Current EPA daily particle exposure limits for PM2.5 and PM10 are 35 and 150 ug/m^3 (EPA, 2014) and particles are of concern in agricultural areas where significant natural air intake is common in unconditioned spaces,

such as wineries. As a result, winery fermentation spaces can present a hazardous environment if the rate of removal by ventilation does not exceed the rate of carbon dioxide release by fermentation and if there is poor air distribution within the building or fermentation hall. They can also be spaces in which outside particle can be introduced during working periods and remain and be redistributed with internal air movements.
The design of fermentation spaces is further complicated by the dynamic emission characteristics of batch ethanol fermentations and by the staggered beginning of fermentation that is usually determined by the grape delivery pattern. The number of active fermentations changes as additional grapes are delivered throughout the harvest period. White wine fermentations normally take 14 to 21 days to complete, while red wines fermenting at higher temperatures are completed within 7 to 10 days. Wine fermentations typically release between 60 to 65 L of carbon dioxide per litre of juice, depending on the initial sugar content (Boulton et al. 1996). The rate of carbon dioxide release is proportional to the fermentation rate and this begins slowly then accelerates to a peak at mid-fermentation and then declines back to zero at the end of the fermentation. In order to remain below the permissible exposure limits for carbon dioxide, the rate of fresh air intake needs to be about 200 times the rate of carbon dioxide release and this poses the major challenge in conventional building design approaches. Most indoor winery fermentation spaces are monitored for carbon dioxide levels but often have only one sensor and some sensors are not installed in optimal air flow locations, even worse is that some fan ventilation systems become ineffective once the room is closed up at the end of the working day.

This project aimed to evaluate the ability of wireless sensor board to monitor the air environment in a space that is densely-populated with stainless steel fermenters in the midst of an existing wireless data network, inside a steel structure. This is the first report of specific information about carbon dioxide, ethanol and particle concentrations in a winery during harvest period and hopefully, it will lead to improved design and control of the ventilation patterns in these unconditioned spaces.

METHODOLOGIES

The winery building chosen for this installation was the LEED Platinum Teaching and Research Winery at UC Davis. Like many commercial wineries, it is an unconditioned fermentation space that relies on open doors for most of its air ventilation during working hours but is closed up during the non-working period. A unique feature of this winery is the capturing of fermentation emissions from all of the fermenters rather than releasing them into the room. The building is a steel-framed, steel-roof structure with one hundred and fifty 200 litre, stainless steel, research fermenters and fourteen 2000 litre, stainless steel, teaching fermenters. Each of the research fermenters sends temperature information and juice density every 15 minutes on a separate wireless network. The sensor board used in this project was located in the centre of the fermentation hall underneath a two meter high catwalk in the middle of two rows of the large fermenters.

A wireless point to point connection using IEEE 802.15.4 communication protocol was implemented. The sensor board contained sensors for volatile organic compounds (Applied Sensors, iAQ-2000), carbon dioxide, temperature and humidity (COZIR, GC-0011) with an adjacent particle counter (Dylos, DC1700) to measure two grades of particles greater than 10 um and smaller than 2.5 um and by difference a measure of the 2.5 to 10 um fraction. The board also controlled the data acquisition and transfer using a PSoC5LP module (CY8C5268AXI-LP047) and XBee transmitter (XBee Pro S1, XBP24-AUI-001). The particle counts were measured every minute and accumulated into a data packet along with air measurements taken every 15 minutes. Data packets are transmitted every 15 minutes to a centrally located receiver (ConnectPort X2) that places it on the cloud. During the experimental period two wireless sensor networks were operational simultaneously in the 2.4 GHz spectral region that operated without causing data loss. In addition to IEEE 802.15.4 network, a wireless network configured in a point to multipoint topology using propriety protocol (Cypress CyFi™ Low-Power RF) supports information collection from the research fermenters.

The carbon dioxide and volatile organic carbon sensors were direct reading in parts per million. The particle counts were converted from the Dylos output of counts per 1/100th of a cubic foot to counts per cubic meter by multiplying by 3531.5. The mass of 2.5 and 10 micron particles was calculated to be 5.8 x 10^{-7} ug and 1.2 x 10^{-4} ug based on the radii reported by Lee et al., 2008 and a particle density of 1.65 g/cm^3. The particle counts were converted into the units of microgram per cubic meter using equation 1.

$$\text{Particle Concentration (ug/m}^3\text{)} = \text{Dylos Number} * 3531.5 * \text{Particle Mass (ug)} \qquad (1)$$

RESULTS AND DISCUSSION

A typical data for the pattern of temperature, carbon dioxide, volatile organic carbon is presented in Figure 1. The daily temperature and humidity values in the hall approach those of the outside air when the doors are open during the day and return to the night time conditions after the doors are closed at the end of the day. The carbon dioxide levels are generally less than 2500 ppm due to the capture system that is installed in this facility. The volatile organic carbon levels which might be expected to be dominated by ethanol are not related to carbon dioxide levels and tend to spike after the building is closed. This may be due to emissions from cleaning solutions (peroxyacetate) or residual wine in drains after tank cleaning. The levels of small and large particles show periodic spikes, Figure 2, and these may be due to night air intake fan activity since it is more pronounced when the building is closed. This pattern is the same over longer periods. Almost all values are below the daily permissible exposure levels and would be acceptable on a time-weighted average basis. The two sizes of particles appear to be independent of each other, suggesting difference sources. This needs to be investigated further.

CONCLUSIONS

The results demonstrate the effectiveness of a wireless sensor system to record the air composition in a winery during harvest. The vapor capture system in this winery keeps the ambient carbon dioxide levels to well below permissible exposure limits. The volatile organic carbon measurements were not correlated with the carbon dioxide levels and show peaks that seem to relate to other winery activities rather than fermentation emissions. The airborne particles can be distinguished into two types a fine particle set and a large particle set that were unrelated to each other.

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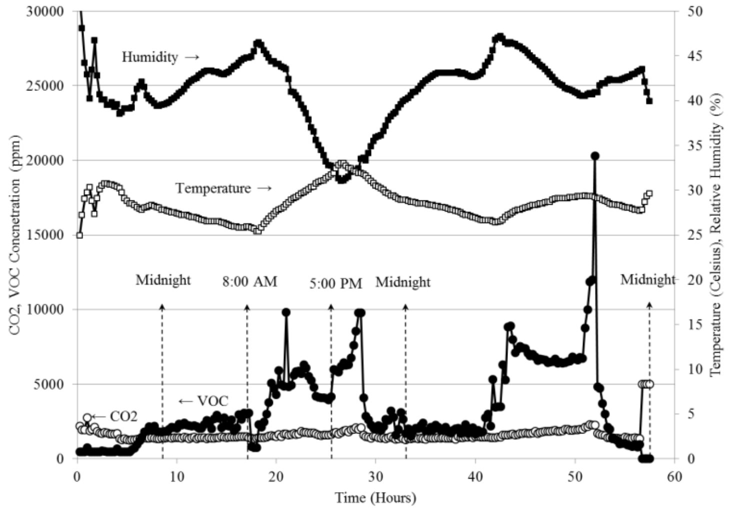

Figure 1. The air temperature, humidity, and concentrations of volatile organic carbon and carbon dioxide during a two day period, during the 2014 harvest.

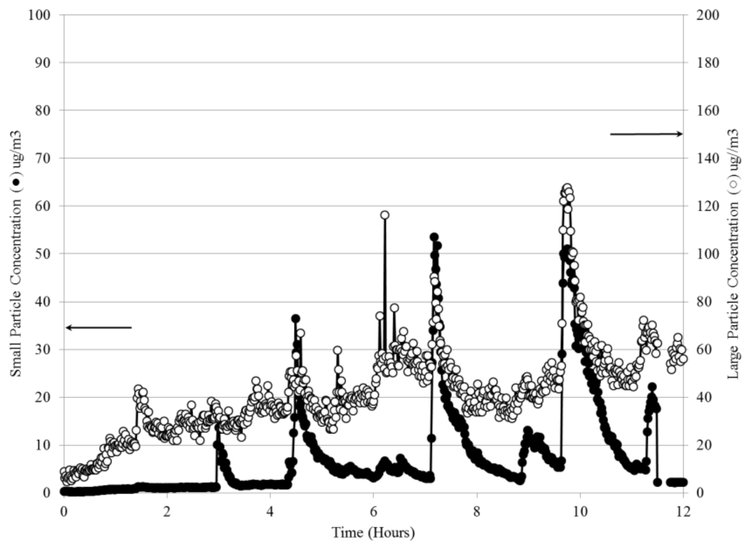

Figure 2. Small and large particle counts during a midday to midnight period.