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Monitoring carbon dioxide levels for early detection of spoilage and pests in stored grain

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Abstract

Elevated CO_2 levels in localized pockets of a grain mass are caused by insects, fungi, and grain metabolism. These hotspots may occur away from temperature cables in bins, silos, tanks and warehouses making early detection of spoilage difficult. For grain stored in ground piles or bunkers that typically do not have temperature cables, considerable economic loss may result in the absence of CO_2 monitoring. The primary objective of this study was to monitor CO_2 levels for early detection of spoilage. Three large tanks and two ground piles were monitored at a commercial grain handling facility (grain elevator) in the Midwestern U.S. Each tank held approximately 12,500 t and the ground piles held approximately 40,000 and 50,000 t of maize each. Four CO_2 sensors each were installed at the top (near the vents) and base (exhaust air stream of fans) of each tank. The CO_2 sensors were connected to master radios that received signals from the sensors and transmitted data wirelessly to a slave radio connected to a PC located in the office about 300 m away. For each ground pile, a sensor was installed in the air stream of several exhaust fans. The study was conducted from April – Sept 2005 in the large tanks and from January – May 2006 for the ground piles. The CO_2 levels ranged from 500 ppm (0.05 %) to 5,000 ppm and higher levels of up to 2.5 % were recorded with a portable CO_2 monitor. The high CO_2 levels were confirmed by the extent of spoilage which ranged from 15 to 25 % when maize was moved out from the large tanks in September 2005. CO_2 monitoring of the ground piles storing newly harvested maize became an important decision-making tool for the operations manager with respect to early detection of spoilage.

Key words: Carbon dioxide, Maize, Spoilage, Ground piles, Tanks, Silos, Stored grain.

Introduction

It has been established in laboratory and field trials that spoiling grain produces high CO_2 levels compared to good quality grain. This is attributed to a combination of various factors such as moisture content of grain, presence of molds,

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insect infestation, and temperature. Detecting and monitoring CO_2 levels in the headspace of a storage structure or at the aeration fan outlets can give an early warning about grain spoilage which may otherwise go undetected with conventional temperature cables. The major constraint of expensive, inaccurate and cumbersome CO_2 sensors from years past has been overcome through technological advances, which have made affordable, accurate and durable CO_2 sensors available at a reasonable cost. It is now possible to use commercially available portable or fixed CO_2 sensors to monitor CO_2 levels in grain storage structures on and off-farm farm in order to get an early warning about spoilage conditions in a grain mass. This enables stored grain managers to take corrective action such as aerating, turning, selling or fumigating the grain.

Purdue University research has investigated the use of CO_2 sensors to monitor early spoilage detection since 1999 (Zagrebenyev et al., 2001; Maier et al., 2002; Bhat et al., 2003; Ileleji et al., 2006; Bhat, 2006). One early study determined the effectiveness of detecting a hot spot primarily due to spoilage of high moisture maize in a stored grain bulk with a CO_2 sensor installed in the headspace of the bin compared to detection with temperature cables. Three experimental trials were conducted in a 12.5-t pilot-scale bin from September 2001 to March 2002. A hot spot in the grain bulk was initiated by dripping a controlled amount of water into a confined grain mass held in five layers of cylindrical mesh trays within the grain bulk. Temperature sensors in the core of the hot spot formation monitored its progress and confirmed biological activity, which paralleled the increasing CO_2 concentration recorded by the CO_2 sensor in the headspace of the bin. CO_2 concentrations in the bin headspace rose from the initial base level of 500 to 1,500 ppm for Trial 1, 1,700 ppm for Trial 2, and 2,300 ppm for Trial 3 and were recorded after 400, 600, and 1,800 h, respectively. There was a strong positive linear correlation between the rise in headspace CO_2 concentration and the parallel rise in temperature recorded by sensors in the core of the hot spot during all three trials. A subsequent series of spoilage detection tests with fixed and portable sensors conducted in 33,000 to 51,000 t grain piles and a 12,500 t cylindrical steel tank with stored maize indicated that CO_2 sensors were effective in detecting the occurrence of spoilage in the stored grain and detected spoilage earlier than temperature cables. Spoilage detection was effective either by measuring CO_2 concentration of the air stream from a negative draft aeration duct with a handheld CO_2 sensor, or by installing a wall-mounted CO_2 sensor in the tank headspace. The results showed that temperature cables alone might not be a reliable indicator of stored grain conditions and CO_2 sensors could be used as an additional complimentary tool for stored grain management.

The primary objective of this study was to further refine and automate the implementation and application of monitoring CO_2 levels for early detection of spoilage in large tanks and ground piles at a commercial grain elevator in the Midwestern U.S.

Materials and methods

Facility

The field trial was conducted at The Andersons facility in Delphi, IN, where maize is received from producers and stored in steel storage tanks (Figure1a), concrete silos, or outdoor ground piles (Figure 1b and c) before being traded in the domestic or global markets. The trials were conducted in three of their five large steel storage tanks. Each welded steel tank has 12,500 t (500,000 bushel) capacity with 34.8 m (114 feet) base diameter, 14.6 m (48 feet) eave height, and 22.9 m (75 feet) total height. In each of these steel tanks about 42,500 t (450,000 bushel) of maize was stored. A second trial was set up utilizing two ground piles. The round pile (Figure 1b) had 45,000 t (1,800,000 bushel) capacity with 97.5 m (320 feet) diameter, and the oblong pile (Figure 1c) had 37,500 t (1,500,000 bushel) capacity with 67.1 m (220 feet) width and 140.2 m (460 feet) length. The initial condition of the maize loaded into the tanks met U.S. Grade #1, which was less than 3 % damage. The quantity stored and the average final grade, moisture content and damage is summarized in Table 1.

CO_2 sensors and communication radios

The CO_2 sensor (OEM Module 6004) modules (Figure 2a) were procured from Telaire Inc. (Goleta, CA) and incorporated into a custom-built design that was encased in a PVC box (0.0762 m x 0.0762 m, Figure 2b). A provision for an external connector to connect the sensor cable to a communication radio was also included. The PVC box had 0.0127 m diameter holes on both sides of the connector through which the air from the exhaust stream or headspace could enter and pass over the membrane of the sensor inside the box. The holes were covered with a mesh (0.1905 mm) to minimize infiltration of dust and particulate matter into the box to avoid clogging the membrane. The radio (Figure 2c) was procured from AgSense, LLC (Huron, SD) and had a provision to connect five sensors and an antenna to transmit data wirelessly to a master radio installed at a base station located in the facility manager's office about 300 m from the tanks. The radios have a range of 20 miles in a clear

(a) (b) (c)

Figure 1. (a) Large steel storage tank storing 42,500 t (450,000 bushel) of maize equipped with a downward draft aeration system. (b) Round pile with a storage capacity of 450,000 t (1,800,000 bushel) and a downdraft aeration system to hold in place the tarp cover. (c) Oblong pile with a storage capacity of 375,000 t (1,500,000 bushel) and a downdraft aeration system to hold in place the tarp cover.

Table 1. Quantity and quality of yellow maize stored in each of the three steel storage tanks and the two ground piles determined after unloading them.

Location	Quantity Stored (t)	Grade of Maize	Moisture Content (W.B)%	Damage (%)
Tank 52	11,250	YC-2	15.5	17.0
Tank 54	11,250	YC-2	15.7	3.0
Tank 55	11250	YC-2	15.7	17.0
Round Pile	42,500	YC-2	15.9	2.9
Oblong Pile	35,000	YC-2	16.3	3.2

line of sight and 15 miles with structural impediments.

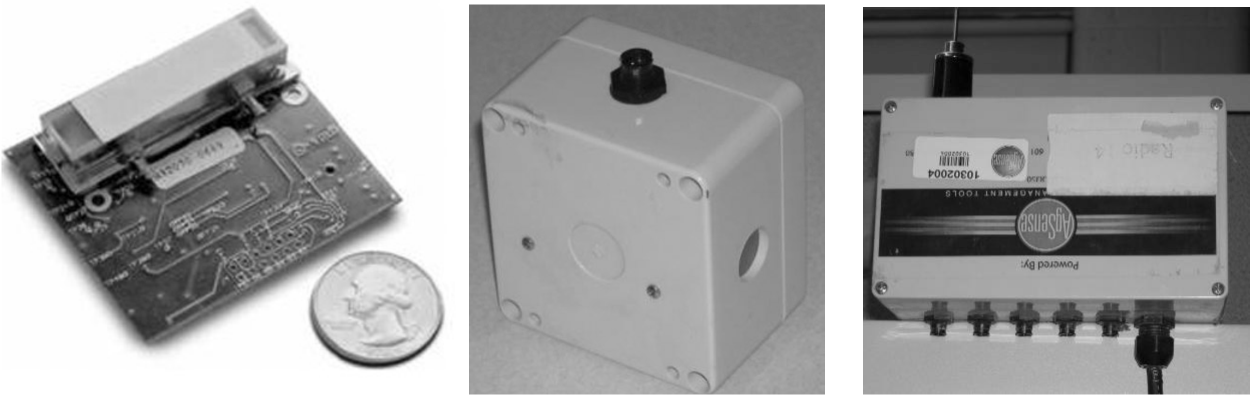
Placement of CO_2 Sensors

In the steel tanks, CO_2 sensors were placed in the headspace and in the fan exhaust air stream of each tank. Four sensors were installed in the headspace through the four roof vents (Figure 3a), and another four sensors were installed on the grating of the exhaust air outlet (Figure 3b). This facility uses downdraft aeration in its tanks. One additional sensor was installed at the eave of tank#55 to monitor ambient CO_2 level.

For the oblong pile, four sensors were installed at the fan exhaust air streams. Each pile end

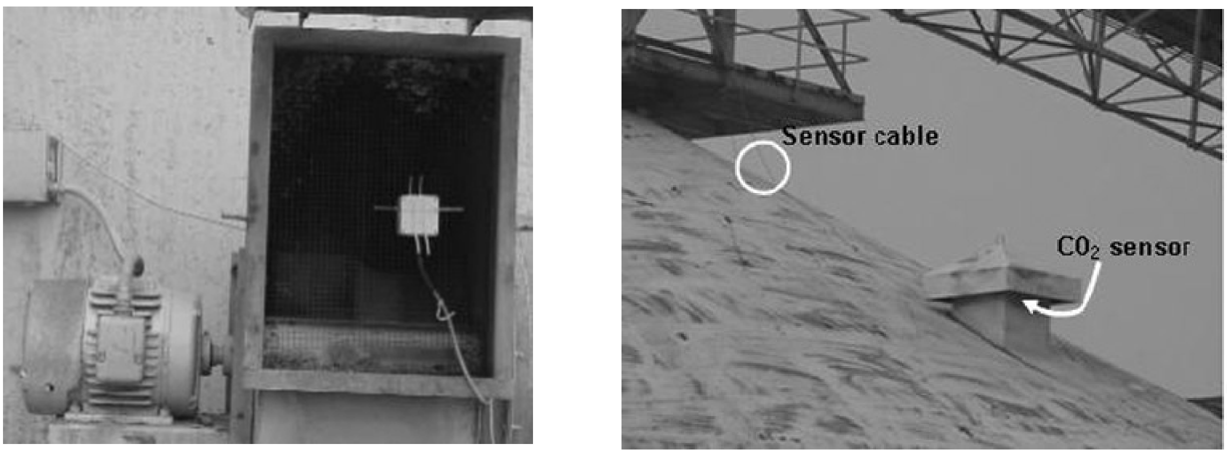
had two sensors on two fans monitoring the exhaust air on a continuous basis. The aeration fans were operated continuously to hold down the tarp covering the pile (Figure 4a).

For the round pile, CO_2 sensors were installed at the exhaust air outlet of four low-speed fan and four high-speed fans (Figure 4b). One additional sensor was installed near the radio to monitor the ambient CO_2 level.



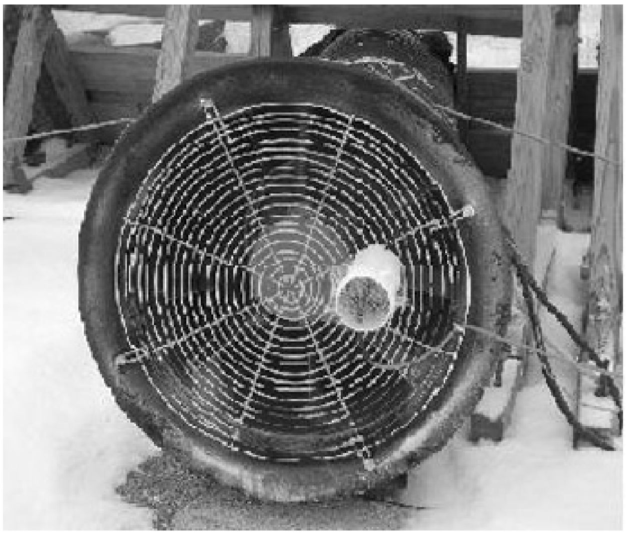
(a) (b) (c)

Figure 2. (a) CO_2 module (OEM 6004, Telaire Inc.) used in the custom-built CO_2 sensors.(b) PVX box (0.0762m x 0.0762m) encasing the CO_2 sensors used in this study. (c) Radio (0.2032m x 0.127m) to receive data from the CO_2 sensors and transfer it wirelessly to a master radio at the base station.



(a) (b)

Figure 3. (a) CO_2 sensor in the air stream of the exhaust outlet of the downdraft aeration fan of the steel tank. (b) Vent location where the CO_2 sensor was placed to monitor headspace CO_2 levels inside the storage tank.



(a) (b)

Figure 4. (a) CO_2 sensor in the air stream of the exhaust outlet of the downdraft aeration fan of the oblong ground pile. (b) CO_2 sensor in the air stream of the exhaust outlet of the downdraft aeration fan of the round ground pile.

Grain Quality Analysis

Two of the tanks, Tank 52 and Tank 55 were filled with maize from the oblong pile and Tank 54 was filled with maize from the round pile. Samples were taken during the transfer of maize from the ground piles to the tanks every 10 truck loads. At each CO_2 sensor location of the oblong ground pile samples were taken using a vacuum probe 0.9 m, 1.5 m and 2.1 m above the exhaust outlet of the downdraft aeration fans once near the end of the storage season.

Samples were analyzed for test weight, moisture content and kernel damage. Samples from the oblong pile were also analyzed by kernel plating. Test weight and moisture content were measured by using a GAC2100 grain analysis computer (Dickey-John Corp. Decatur, IL, USA)

The extent of kernel damage was evaluated using sieves. One hundred gram samples were shaken for 30 seconds using a 6.35 mm diameter round–hole sieve. The kernels remaining on the sieve were weighed using an electronic balance. The kernels that passed through the first sieve were again sieved using a 4.76 mm diameter round-hole sieve. The kernels remaining on this second sieve were inspected and immature kernels and foreign material were removed. The weight of the material remaining on the sieve was weighed again. The weight of material that passed through the sieves, and the material removed from the sieves were determined. Three trials were conducted on each sample and the total percentage of foreign material removed was averaged.

Kernel plating involved surface sterilizing kernels by exposure to 6 % NaOCI (bleach) for one minute and for another minute washing twice with deionized water. Ten kernels were placed in each of twenty Petri dishes that contained 6 % malt salt agar (Tuite et.al., 1985). The dishes were placed in a room at 29 °C and after seven days of incubation, the number of kernels invaded by fungi was determined.

Results and conclusions

Steel tanks

The data collected for Tank 54 showed the benefit of using CO_2 sensors for early detection of spoilage (Figure 5a and Figure 5b). The maize was dry (15.7 %) with an initial percent of 3 % damage. As seen in Figures 5a, the CO_2 levels in the headspace of this tank steadily climbed from 500 ppm to 5,000 ppm by the second week of June while the headspace temperature increased to 21 °C (70 °F). One of the sensors (Sensor 2) showed an early peak of 3,500 ppm in the first week of May while the other two sensors indicated about 1,000 ppm. This was probably due to increased spoilage activity at a localized spot below the grain surface nearer to Sensor 2 than the other sensors. This localized hot spot coupled with rising ambient temperatures likely contributed to higher CO_2 levels reaching 5000 ppm by the end of June 2005. Compared to the other two tanks, the maize in this tank was of better initial quality with only 3 % damage compared to 17 % for the other two tanks. The increased CO_2 levels in this tank compared to the other two tanks cannot be satisfactorily explained. The aeration fans for this tank were started on May 11 resulting in reduced CO_2 levels as CO_2 was flushed out. The aeration fans were again started on June 12 showing a decline in CO_2 levels but apparently fans were not run long enough to flush out the accumulated CO_2 levels. On resumption of data collection on July 26, high CO_2 levels persisted while ambient temperature reached 26.7 °C (80 °F). The aeration fans were run on August 11 and as well as September 03 showing corresponding decreases in CO_2 levels. The maize from this tank was subsequently transferred back to the outdoor ground pile between 12 -20th September. The percent damage of samples collected during that transfer process showed 5 % damage, which was a 2 % point increase and a sign that maize had deteriorated somewhat.

The CO_2 sensors at the air outlets at the bottom of the tank showed a peak of 2000 ppm in the 2nd week of May (Figure 5b).The effect of flushing CO_2 from the tank was clearly seen when the aeration fans were started on May 11. Afterwards, the CO_2 levels held steady within 400-600 ppm for two weeks before starting to climb and reaching a peak of 4200 ppm in the 2nd week of June. The aeration fans were started again on June 12 for approximately 8 h, which initiated the decrease in CO_2 levels. Why the levels reached near ambient concentrations after nearly a week without additional aeration remains unclear. The CO_2 peaks observed during the months of July and August ranged from 1,800 – 2,500 ppm. Operation of the aeration fans had the same effect as in the headspace, i.e., a substantial decrease in CO_2 levels. The average grain temperature monitored with the temperature cables at a depth

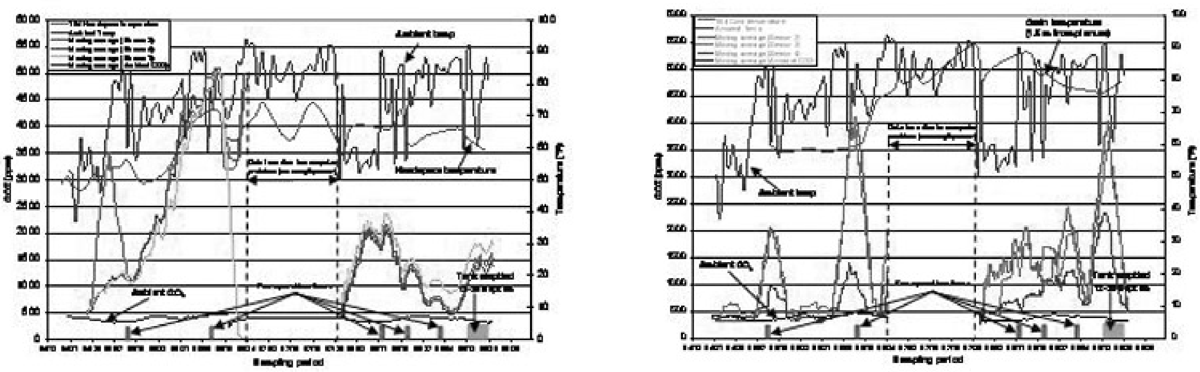


Figure 5. (a) Mean CO_2 levels recorded by sensors inside the roof vents in the headspace of Tank 54 with average ambient temperature, fan operation periods, and tank unloading days between April 21 and September 20, 2005.(b) Mean CO_2 levels recorded by sensors in the air stream of the exhaust outlet of the downdraft aeration fans of Tank 54 with average grain temperature 1.5 m above the floor, average ambient temperature, fan operation periods, and tank unloading days between April 21 and September 20, 2005.

of 1.5 m above the floor did not show a strong correlation with the CO_2 levels observed. The temperature data for the period April 21 to May 11 to compute average grain temperature were not available.

The CO_2 sensors installed in the headspace near the roof vents and in the air stream of the exhaust aeration fans detected increasing CO_2 levels beginning in June 2005 as the ambient temperature increased. The operation of down-draft aeration fans as a corrective managerial decision to reduce CO_2 levels was successful. The plenum CO_2 sensor levels clearly indicated a steady rise in CO_2 levels by the first week of June 2005. However, the avearge temperature of the grain mass at a depth of 1.5 m from the floor did not indicate any spoilage (no increase in temperature) compared to the peaks of CO_2 levels observed. The CO_2 technology as an “early warning system” of grain spoilage was confirmed to be a viable alternative to the temperature-only monitoring system.

Ground Piles

Based on data collected from January to May 2006 for the round pile, CO_2 levels did not increase noticeably at most locations that CO_2 sensors were installed. CO_2 levels of 350-500 ppm measured at the eight locations of the round pile were almost the same as the ambient CO_2 levels from January to May while the ambient CO_2 level showed about 400 ppm. Data for each location was consistent and did not vary much.

CO_2 levels measured from the oblong pile indicated high concentrations at one west end location (Fan 3, Table 2). CO_2 levels measured monthly at Fan 3 showed a slight increase from about 1,000 ppm to over 1,200 ppm while CO2 levels at the other three fans remained steady between 500 – 850 ppm. Upon unloading of the grain, quality analysis confirmed higher levels of damage of grain located near Fan 3.

Grain quality analysis

Samples were collected from all locations where CO_2 sensors were installed on the oblong pile. By Kernel plating, the primary fungi species present in the grain samples were determined. High fungal counts on samples from the Fan 3 location correlated well with the high CO_2 levels detected (Table 3).

Conclusions

Our results showed that temperature cables alone might not be a reliable indicator of grain conditions in storage structures. The CO_2 monitoring technology was confirmed as a viable alternative to temperature-only monitoring for “early warning” of grain spoilage especially also in outdoor ground piles where temperature monitoring is not an option.

Our results also showed that CO_2 levels correlated with the growth of fungi species known to cause visible mold damage on grain kernels, Thus, increasing CO_2 levels can give operations managers important information for making better decisions to protect grain quality and prevent early spoilage.

Table 2. Monthly CO_2 levels at four fan locations of the oblong pile between January and March 2005.

	CO_2 Concentration Level (ppm)			
Month	Fan2	Fan3	Fan8	Fan9
January	748	1,042	699	650
February	847	1,148	700	690
March	533	1,233	712	633

Table 3. CO_2 level, kernel infection, visible mold growth and kernel damage in samples taken from vacuum probed samples of the oblong ground pile.

	Location			
Type	Fan2	Fan8	Fan9	Fan3
CO_2 Level		Normal		High
Kernel Infection	*Penicillium* sp (2 % infected kernels)			*Fusarium* sp (13 %)
	Fusarium sp (10 %)			*Eurotium* sp (7 %)
	Eurotium sp (5 %)			Other molds (10 %)
	Other molds (2 %)			
Visible mold growth And kernel damage in The samples		No		Yes

Aknowledgements

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