0702

Early Detection of Spoiled Grain Stored in Hermetic Plastic Bags (Silo-bags) Using CO_2 Monitoring

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Abstract: In Argentina about 35 million tonnes of grains were stored in hermetic systems (silo-bags) during 2007, and it is expected that in the future a bigger proportion of the grain will be stored in these silo-bags in Argentina and other countries.

The silo-bags are made of a 235 – micrometer plastic film of 2.74 m diameter and 60 m long (holding approximately 200 tonnes of wheat each). Grain quality monitoring is carried out with a standard torpedo probe. This operation has several disadvantages, including perforating the plastic film (disturbing the air tightness of the system), difficulties to target the grain spoilage area (especially when it is located in the bottom of the silo-bag), and the relatively intense labor demand. Monitoring stored grain conditions through temperature measurement is not an option, since the grain stored in the silo-bags does not increase temperature during spoilage.

A study was made with several silo-bags filled with wheat and soybean located at different farms and grain elevators in the South-West of Buenos Aires province. The silo-bags were sampled with a torpedo probe, and the corresponding value of CO_2 concentration of the silo-bag was measured. The collected grain samples were analyzed in the laboratory for moisture content (MC). Additionally, the silo-bag overall condition was evaluated (bad sealing, openings, occurrence of occasional flooding in the area of the silo-bag, etc), and evidence of spoiled grain at bag unloading was collected.

Periodic CO_2 monitoring of silo-bags allowed for the early detection of biological activity and spoiled grain. A distinctive value of CO_2 for different MC grains was established, which represents the typical atmospheric composition for a silo-bag with and without conservation problems. The silo-bags holding grains with different levels of conservation problems were identified by the unusually high CO_2 concentrations of the modified atmosphere.

Key words: modified atmosphere, biological activity, grain preservation

Introduction

In year 2007 about 35 million tonnes of grains, including soybean, corn, popcorn, wheat, sunflower, malting barley, rice, sorghum and cotton seeds were stored in hermetic systems (silo-bags) in Argentina. The end use of these crops varied from feed, wet and dry milling, seed, human consumption, brewery, oil extraction and flour milling among others.

Each silo-bag can hold approximately 200 tonnes of wheat (180 tonnes of soybean) and with the handling equipment currently available the loading and unloading operation is fast, simple and totally mechanized. These plastic bags are 60 m long, 2.74 m diameter and the plastic cover is made of three layers (white outside and black inside) with 235 micrometers of thickness.

Measuring grain temperature is the main tool used by farmers and the grain industry for monitoring proper storage conditions, since an increase in grain temperature is highly correlated with an increase in the biological activity in the grain mass. Unfortunately, this technology is not useful for monitoring storage conditions in silo-bags. It was demonstrated that temperature of the grain stored in silo-bags follows the pattern of the average ambient air through the seasons, presumably due to the high surface/volume ratio of the silo-bag, compared to a regular steel silo (this would provide the silo-bag with a high capacity to exchange heat with the air and soil)[1]. The surface/volume ratio of a 180 tonnes silo-bag is approximately 1.42, while for a standard metal bin of the same capacity (7 m diameter and 9 m height) the ratio is 44 % lower (0.79). Thus, the effect of the biological activity on grain temperature can be obscured by the ambient air temperature effect.

Monitoring the grain storage condition by probing the silo-bags with standard torpedo

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probes is a process fairly easy to implement. However, each perforation made to the plastic cover disturbs the air-tightness of the system, which limits the number of samples that can be collected from each silo-bag, and the sampling frequency. Additionally, this monitoring procedure is useful in order to obtain an idea of the overall quality of the grain stored in the silo-bag (i.e., protein content, falling number, etc), but it is not suitable for detecting early spoilage problems (most of the spoiled grain process occurs in particular locations of the grain mass, typically in the bottom of the silo-bag where the torpedo probe cannot collect the sample). Another disadvantage of this methodology is the amount of labor and time involved.

The silo-bags are waterproof and have a certain degree of gas-tightness (oxygen (O_2) and carbon dioxide (CO_2)). As a result, respiration of the biotic components of the grain mass (fungi, insects, and grain) increases CO_2 and reduces O_2 concentrations. Thus, the degree of modification of the gas composition in the interstitial air could be related to the biological activity inside the silo-bag, and can be used as a monitoring tool to detect early spoilage problems.

Cardoso et al. [2] and Rodr guez et al. [3] studied the main factors affecting CO_2 concentration in wheat and soybean stored in silo-bags. Based on these research studies the typical CO_2 concentration of wheat and soybean stored in silo-bags without conservation problems was established. This study is about detecting conservation problems in wheat and soybean stored in silo-bags by comparing the measured CO_2 concentration with the typical CO_2 concentration values of silo-bags without conservation problems.

Materials and Methods

The tests were carried out in elevators and farms in the south east of Buenos Aires province, Argentina. The silo-bags were filled with fresh grain right after the harvest in the same plots where the crops were planted, or filled with grain coming from bins in the proximity of the elevator facility. The experiment started in January for wheat and in April-May for soybean and lasted until the silo-bags were opened for emptying (about 5 months later).

For each silo-bag two sampling locations were established. The procedure consisted of measuring first the CO_2 gas concentration with a portable gas analyzer (PBI Dan Sensor, CheckPoint, Denmark), perforating the plastic cover with a needle. The gas composition was analyzed for three levels in each sampling location, close to the top of the bag, at the middle and close to the bottom.

In each sampling location grain was collected from three different levels (top = 0.10 m depth, middle = 0.75 m depth, and bottom = 1.6 m depth. Total height of the bag = 1.7 m) using a standard torpedo probe and grain MC was measured (GAC 2100, Dickey – John). After probing the silo-bags the openings were sealed with a special tape in order to restore the air – tightness.

The monitoring procedure was repeated approximately every 15 days during the entire storage period. When the grain was unloaded from the silo-bag, both grain and bags were inspected to detect spoiled grain. The silo-bag was then classified as "No evidence of storage problems" or "Evidence of storage problems" (Fig. 1).

Fig. 1 Silo-bag with spoiled grain detected during unloading.

Results and Discussion

Figure 2 shows the change of CO_2 concentration in three different silo-bags with soybean at 11.5% MC (below market MC), at 12.9% MC (close to market MC), and 14.9% MC (higher than market MC) (13.5% is the base MC for marketing according to the soybean argentine commercialization standard). During the winter time (July – August) the CO_2 concentration was below 3% for all MCs. In the early spring (September) the CO_2 concentration started to increase to 9 and 10% for the silo-bags with 12.9% MC and 11.5% MC, respectively. In October, the CO_2 concentration increased even further, up to 16% and 18% for the same silo-bags, respectively. From then on, the CO_2 concentration decreased to about 10 to 13% and remained stable during the late spring (December). The silo-bag with wet soybean (14.9% MC) had a CO_2 concentration lower than 2% during the entire storage period. When the silo-bags with high CO_2 concentration were unloaded a significant amount of grain with severe spoilage was detected. In these two bags, a layer of 0.1 m thick at the bottom was affected by perforations in the plastic cover. This allowed the entrance of water and oxygen, creating suitable condition for mold development when the grain temperature increased in the early spring. On the other hand, the wet soybean silo-bag did not present any significant perforation in the plastic cover, so the safe storage conditions were maintained throughout the entire storage period, even during the late spring. As a result, the grain did not show any evidence of spoilage when inspected during the unloading operation.

These results showed that periodic CO_2 monitoring can be used as a tool for early detection of spoilage problems in silo-bags.

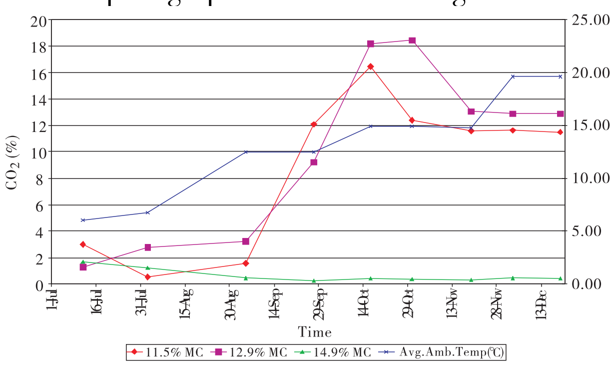

Fig. 2 CO_2 concentration during storage time of three silo-bags with soybean at 11.5% MC, at 12.9% MC and at 14.9% MC and average ambient air temperature.

Although the periodic monitoring of the CO_2 concentration allows for detecting an increase of biological activity in silo-bags during storage (Fig. 2), sometimes there is only opportunity to make a single measurement of the CO_2 concentration of the silo-bag. In this case, there is no possibility to compare results with previous values in order to determine whether the biological activity was increasing, and the grain storage condition turned unsafe. For these situations another type of approach is needed to relate CO_2 concentration with grain storage condition.

Figure 3 shows that the average CO_2 concentration for wheat silo-bags with proper storage conditions was substantially lower than the average concentration for those silo-bags with evidence of spoiled grain. At MC values below 13%, the difference between the two lines was about 10% percentage points of CO_2, while at 16% MC the difference was reduced to 7.5 percentage points. It was observed that for those silo-bags with wheat MC below 16%, the spoiled grain was localized in the bottom grain layers. In these silo-bags several perforations were observed in the plastic cover, which allowed the entrance of moisture (from rainfall) and oxygen. The perforations were caused by wild animals (armadillos), or because the silo-bag was settled on top of the residues of the previous crop (the stems perforate the silo-bag if proper care is not taken during the placement and loading operation). Another reason was improper sealing of the end of the silo-bag, which allowed the entrance of moisture and oxygen to the system. Finally, some silo-bags were placed in low lands, which were flooded after an intense rainfall. In this last situation, even an undamaged and well sealed silo-bag was affected.

On the other hand, when the wheat MC was above 18%, spoilage was observed in the silo-bag regardless of the silo-bag's structural condition (perforations or improper sealing of the ends). The excessively high grain MC resulted in high mold activity, which caused grain spoilage. Water deposition was observed at the bottom of these silo-bags, even in those bags without visible perforations. It was speculated that condensation occurred due to the day – night temperature differential. The recurrence of this process could result in significant water deposition on the inside of the plastic cover, which could produce a large amount of spoiled grain.

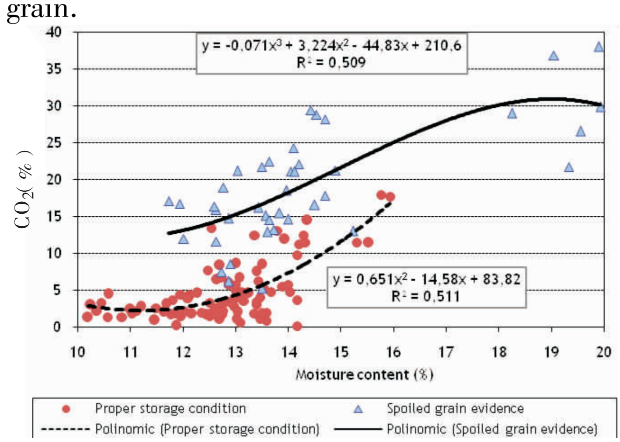

Fig. 3 CO_2 concentration at different moisture contents in wheat silo-bags with storage condition classified as "proper" and with evidence of spoiled grain.

Figure 4 shows that the average CO_2 concentration for soybean silo-bags with proper storage conditions was substantially lower than the average concentration for those silo-bags with evidence of spoiled grain. Those silo-bags with soybean under proper storage conditions always presented CO_2 values below 4%, and did not show a trend to increase CO_2 concentration with the increase of MC. On the other hand, silo-bags with evidence of spoiled soybean resulted in CO_2 concentrations as low as 6% and as high as 18%, and the average between 11.5% and 14% CO_2. Contrasting with the wheat data, there was not a clear trend to correlate the increase in CO_2 concentration with the increase of MC, neither for those bags with grain with proper storage conditions, nor for those bags with evidence of spoiled grain. The reasons that caused the grain spoilage were similar to those described for wheat silo-bags as it allowed for the entrance of moisture and oxygen: perforations in the plastic cover, improper sealing, or temporary flooding of the ground.

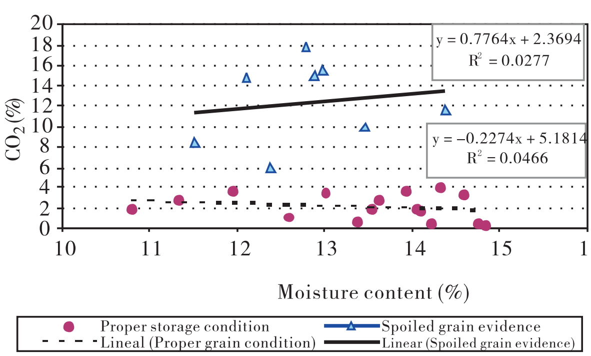

Fig. 4 CO_2 concentration at different moisture contents in soybean silo-bags with storage condition classified as "proper" and with evidence of spoiled grain.

Based on these results, the authors propose to use CO_2 monitoring for detecting spoilage problems in wheat and soybean silo-bags. In the case of wheat silo-bags, the operator measures the CO_2 concentration and collects a grain sample to determine the MC. The typical CO_2 concentration for safe wheat storage condition (at the measured MC) is obtained from Figure 3, and then compared to the measured CO_2 concentration. If the measured CO_2 concentration is below the typical CO_2 concentration, the storage condition can be classified as "safe". On the other hand, if the measured CO_2 concentration is above the typically safe CO_2 concentration, the storage condition is classified as "risky" and the operator should monitor that silo-bag closely to discard spoilage. If the measured CO_2 concentration is close or above the typical CO_2 concentration of a spoiled silo-bag, then the storage condition should be classified as "unsafe" and immediate action should be taken (i. e., unloading the silo-bag).

In the case of soybean silo-bags the grain MC is not critical to determine storage conditions (for soybean MC range between 11% and 15%), and when the measured CO_2 concentration is above 4%, the storage condition of the silo-bag should be classified as "risky". When the CO_2 concentration is close or above 11.5% – 14%, the storage condition of the silo-bag should be classified as "unsafe". Otherwise the silo-bag storage condition should be classified as "safe" (CO_2 concentration below 4%).

Conclusions

Periodic monitoring of CO_2 concentration can be used as a tool for detecting an increase in the biological activity in silo-bags and relate it to the spoiling grain process.

The expected CO_2 concentration of wheat and soybean silo-bags with safe and unsafe (evidence of spoiled grain) storage conditions was determined.

This methodology can be used for monitoring grain storability in silo-bags. The CO_2 concentration in the silo-bag is measured and compared to the expected CO_2 concentration for silo-bags with safe and unsafe storage condition, and the silo-bag storage condition is then classified as safe, risky and unsafe.

The CO_2 concentration of wheat silo-bags with safe storage conditions increases with grain MC (from lower than 5% CO_2 for 13% MC or less, to 17% CO_2 for 16% MC). Thus, the comparison of the measured CO_2 concentration with the typical CO_2 concentration of silo-bags at safe storage conditions should be related to the grain MC.

On the other hand, the MC of soybean does not substantially affect the CO_2 concentration of silo-bags with safe storage conditions (for MC soybean MC range from 11 to 15%), so any measured concentration below 4% means safe storage conditions, between 4% and 12% means "risky" storage conditions, and above 14% means "unsafe" storage condition.

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