



## Silo Gases in Large Scale Pile Silos

*P.H. Robinson*

Cooperative Extension Specialist

University of California, Davis, CA 95616-8521

Silo gases have been a killer for as long as farmers have preserved their crops as silage to facilitate its later feeding to cattle. However many California custom forage choppers, silage pile coverers and farmers think of silo gas risks to humans as an Eastern US issue where silages are commonly put up in upright or pit silos where the gases can accumulate in confined spaces. Due to the 'open' nature of large silo piles in California, many industry people consider silo gas accumulation, and its risks to humans, to be minimal with large silage piles. However this can be far from true since the very large size of many pile silos in California means that when silo gases occur, they can occur in quantity.

### What are silo gases?

Definitions of silo gases vary, but most include carbon dioxide (CO<sub>2</sub>), as well as several oxides of nitrogen (N), of which nitrogen dioxide (NO<sub>2</sub>) is generally considered to be the most important.

### *Typical low level silo gas release from a recently covered silage pile*



CO<sub>2</sub> is always produced during normal silo fermentation and this is highly desirable as it displaces O<sub>2</sub> in the silage mass thereby preventing aerobic micro-organisms, which is associated with silage deterioration, from growing. It is only when CO<sub>2</sub> accumulates in the air which is breathed by a person that the CO<sub>2</sub> become dangerous.

There are several oxides of N which can also be produced during silo fermentation. However they all originate from nitrates, which can accumulate in many crops prior to harvest (see below). Nitrates in the chopped plants are first converted to nitrites and then to ammonia by bacterial action in the silo. Ammonia is also created in the silo mass from degradation of proteins in the crop. As nitrates and nitrites are not gases, they are not classed as silo gases. In contrast, ammonia – a gas at normal environmental temperatures – is generally also not classed as a silo gas because of the relatively low levels associated with silage fermentation, as well as its high water solubility. Ammonia has a sharp pungent odor, and it is commonly added to cleaning products. However in the presence of oxygen (O<sub>2</sub>), ammonia can convert to nitrous oxide (NO) which is a colorless gas with a slightly sweet odor that can dissipate from the silage mass. Harmless to humans, NO is best known as ‘laughing gas’ and, at one time, was widely used as an anesthetic and analgesic in surgery and dentistry. Because NO has no known negative effects on humans, unless inhaled at levels much higher than would be associated with silage fermentation, NO is also not classed as a silo gas.

*A typical silo gas release area showing the discolored crop*



*Similar areas of gassing are also often visible on silage pile ramps left overnight.*

However if NO accumulates in the silage mass, it can be converted to NO<sub>2</sub> in a reaction with O<sub>2</sub>, which can also be released from the silage mass. In contrast to NO, NO<sub>2</sub> gas has an orange color with a chlorine-like odor. At low levels in ambient air, the orange color will appear yellow. Thus as the concentration of NO<sub>2</sub> in air increases, the air color will

shift from clear to a bright orange. Because of its negative effects on human health (see below)  $\text{NO}_2$  is classed as a silo gas. If  $\text{NO}_2$  accumulates in the silo mass it can be converted to dinitrogen tetroxide ( $\text{N}_2\text{O}_4$ ), which is also an orange gas with a pungent aroma. Because of its negative effects on human health (see below)  $\text{N}_2\text{O}_4$  is also classed as a silo gas. The final major oxide of N which can be created in silage is dinitrogen trioxide ( $\text{N}_2\text{O}_3$ ) through a reaction of  $\text{NO}$  and  $\text{NO}_2$ . This gas has a blue color and, in spite of a high solubility in water, is also classed as a silo gas. The combination of its blue color and the orange color of  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  can lead to various shades of red in silo gas. All of these oxides of N are heavier than air and so they tend to 'walk' along the ground in a small cloud. They can appear to be almost alive in their movement on a still day.

***High level silo gas release from a recently covered silage pile***



***Note the opalescent appearance of the silo gas caused by early morning sunlight behind it and how the gas 'falls' into the ditch (as it is heavier than air) and 'moves' to the lower area of the corrals. This silo gas is moving from the pile (right) to the corrals (left).***

**Why are silo gases dangerous?**

Silo gases can kill people, although this is very rare in California, but they are more likely to harm people, although they do so in different ways.  $\text{CO}_2$  is ubiquitous in the atmosphere and is a normal part of the carbon cycle. However when it accumulates in a confined space, such as a tower silo, it can cause death by asphyxiation if a person were to enter the silo and climb down into the  $\text{CO}_2$  enriched atmosphere. Colorless and odorless, high levels of  $\text{CO}_2$  simply causes a person to pass out due to a lack of oxygen ( $\text{O}_2$ ), which is displaced from the atmosphere due to the accumulation of  $\text{CO}_2$ . This means that  $\text{CO}_2$  is less likely to be an issue of concern in California style pile silos as it will readily dissipate to ambient air since there is no confined area for it to accumulate in.

In contrast to  $\text{CO}_2$ ,  $\text{NO}_2$  and other oxides of N bind to hemoglobin in the blood after inhalation and absorption through lung tissue. This leads to formation of methemoglobin

(in place of normal hemoglobin), which results in an impaired ability of the blood to transport oxygen. This effect occurs very quickly and, especially if combined with a CO<sub>2</sub> enriched atmosphere, can cause a loss of consciousness extremely quickly. However if a person breaths air with low levels of oxides of N, some of those oxides (i.e., NO<sub>2</sub> and N<sub>2</sub>O<sub>4</sub>) react with water on the surface of the lung to create nitrous acid, which will cause inflammation on the short term and, over long periods, degrades lung function, which may not become clinical for decades.

***High level silo gas accumulation due to creation of an enclosed area***



**Symptoms of silo gas toxicity?**

Issues related to excess accumulation of CO<sub>2</sub>, and asphyxiation, are generally not an issue with large California style piles, for the reasons outlined above. Thus most symptoms of silo gas toxicity with silage piles are related to the oxides of N, and can be broadly divided into those caused by creation of methemoglobin and those caused by creation of nitric acid in lung tissues. If methemoglobin is created, then typical symptoms are those associated with a lack of O<sub>2</sub> such as shortness of breath, rapid breathing, fast heart rate and light-headedness. These symptoms will dissipate once the methemoglobin is replaced by hemoglobin after exposure of the person to the oxides of N in the air ends. However if nitric acid is created on lung tissues, typically associated with exposure to air with a higher level of silo gases, then symptoms include coughing (of fluids created in the lungs) and

wheezing, chest pain, sweating and fever – basically symptoms of acidic conditions on the lung surface. While these symptoms will pass, generally within 36 hours, the damage to lung tissue is irreversible and, if low level exposure occurs frequently over time the ability of the person to breathe normally will be permanently degraded – especially later in older age as lung function often normally degrades.

### **When do oxides of N formation occur in a silo mass?**

It is not uncommon for a farm to not experience a silo gas event for years and then, seemingly without warning, have a serious event. Silo gas formation and release from the silage mass typically occurs within 6 hours of packing and is complete with 48 to 72 hours. As outlined above, two of the key reactions which lead to production of oxides of N require O<sub>2</sub> (i.e., creation of NO and creation of NO<sub>2</sub>). Thus once the O<sub>2</sub> in the ensiled mass has been consumed by aerobic bacteria, generally within this 48 to 72 hour period from packing, production of the oxides of N stops and they dissipate with time.

While there are a number of pre-disposing factors which increase the risk of silo gas (oxides of N) production, its appearance is often unexpected. A key risk factor to silage gas production is the nitrate level in the crop at ensiling. This is because the N in the nitrate, which converts to nitrite and then ammonia which leads to NO and NO<sub>2</sub>, is a key source of the N in the NO<sub>2</sub>. Thus any factors which increase crop nitrate levels can be expected to increase the probability of creation of oxides of N in the ensiled mass. Some risk factors to increased nitrate levels in crops include high levels of N fertilization (including manuring), harvest under cloudy conditions when plant photosynthesis is low, and droughty conditions at harvest which inhibits metabolism of nitrates by the plant. In addition, practices which delay bacterial use of O<sub>2</sub> in the fresh silage mass, such as low density packing (and/or uneven packing) as well as slow coverage with plastic will allow more oxides of N to be created for a longer period of time.

### **What should I do if I see or smell silage gas?**

In large silage piles there is no opportunity to stop the gassing. However it is critical that affected areas be cordoned off and well-marked so that persons unfamiliar with silo gases, and possibly intrigued by the odd yellow/orange gas, do not wander into the affected areas. This is particularly important if workers are coming on-shift during hours of darkness when the gases will be invisible. If some farm operations in the affected area cannot be terminated, then persons entering the area should use an approved self-contained breathing apparatus. In the case of exposure to high levels of silo gases in the air, leading to discernable symptoms as noted above, the person should immediately seek medical care.

Occasionally the production of silo gases will be so rapid that the cover plastic bulges out to create gas pockets. This is particularly the case if the pile has been covered with only a part of the weights needed to hold the plastic down.

**Is there cause for silo gas concern in large California style silage piles?**

This is not likely due to accumulation of CO<sub>2</sub> due to its rapid dissipation to ambient air. Although cases of death or hospitalization due to silo gas (i.e., oxides of N) exposure are very rare in California, the long term effects on lung health of repeated low level exposure are underestimated, especially by pile packers, coverers and feeders. Much more effort should be made to prevent breathing air contaminated with silo gases.

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*P.H. Robinson is a Cooperative Extension Specialist responsible for dairy cattle nutrition and nutritional management. He can be reached at: (530)754-7565(voice) or (530)752-0172(fax) or [phrobinson@ucdavis.edu](mailto:phrobinson@ucdavis.edu) (e-mail) or [animalscience.ucdavis.edu/faculty/robinson](http://animalscience.ucdavis.edu/faculty/robinson) (web).*