WAVELENGTH ELECTRONICS

# Ammonia Gas Detection With Laser Absorption Spectroscopy for Livestock



## ABSTRACT

Researchers from China have developed a laser absorption spectrometer for high precision ammonia gas detection in livestock and poultry housing. Two different techniques are discussed: Open path laser absorption spectroscopy (OPLAS) and tunable diode laser absorption spectroscopy (TDLAS). Both of these detection setups provide theoretical basis and technical support for precision air quality detection and control for this application. TDLAS achieves ammonia detection concentrations of lower than 5 ppm using harmonic absorption signals in the long path gas absorption well with total path length traveled for the light around 4.3 m. Laser absorption spectroscopy has similar results to other gas detection methods, while providing rapid and precise gas detection in portable systems. Accurate and sensitive gas emission measurements can improve the health and safety of livestock and workers.

## LIVESTOCK GAS EMISSION

Gas emissions from large-scale livestock facilities increase directly with operation growth due to animals' breath, waste fermentation, and the physical decomposition of the waste.[1,2] The two major emissions from farm and livestock housing bedding and structures are ammonia ($NH_3$) and methane ($CH_4$), and both of these emissions can vary due to housing type, season, and temperature outside and inside the facilities.[3] Carefully designed ventilation systems in the housing, new feeding strategies, and efficient animal waste disposal can reduce and potentially eliminate sicknesses in the animals due to over-exposure to the emitted gases as well as maintaining healthy workers and keepers.

Although different gas measurement methods and approaches are used for individual farms around the world, trends in gas emissions can be observed regardless of size, breed, conditions, and animal productivity. A recent study[3] in 2019 provides a comparison of 44 publications from 11 different countries regarding the effects on $CH_4$ and $NH_3$ from housing type, air temperature, and floor type. This study concluded that $NH_3$ emissions, relating to Livestock Units (LU), are lower for tied housing than for loose housing with the median emissions of 6.9 g $LU^{-1}$ $d^{-1}$ and 29.3 g $LU^{-1}$ $d^{-1}$, respectively (1 LU = 500 kg live weight and d = day). Floor type differences showed no effect on $NH_3$ or $CH_4$ emissions. Higher air temperatures proved to influence the amount of both $NH_3$ and $CH_4$ emissions, increasing the $NH_3$ emissions from one study from 24.7 g $LU^{-1}$ $d^{-1}$ to 59.4 g $LU^{-1}$ $d^{-1}$ with the starting and ending temperature of 4.7ºC and 18.2ºC, respectively.[3]

Another $NH_3$ study[4] measured the effect of season and temperature on gas emissions from manure facilities. **Figure 1** shows the mean daily emissions and mean background concentration ($C_{BG}$) of one farm in Indiana and one farm in Wisconsin. This, for both the WI and the IN farms, shows the influence of the environmental conditions on the mean daily emissions. **Table 1** further shows the daily $NH_3$ emission per livestock head and per animal unit (AU = 500 kg live mass).

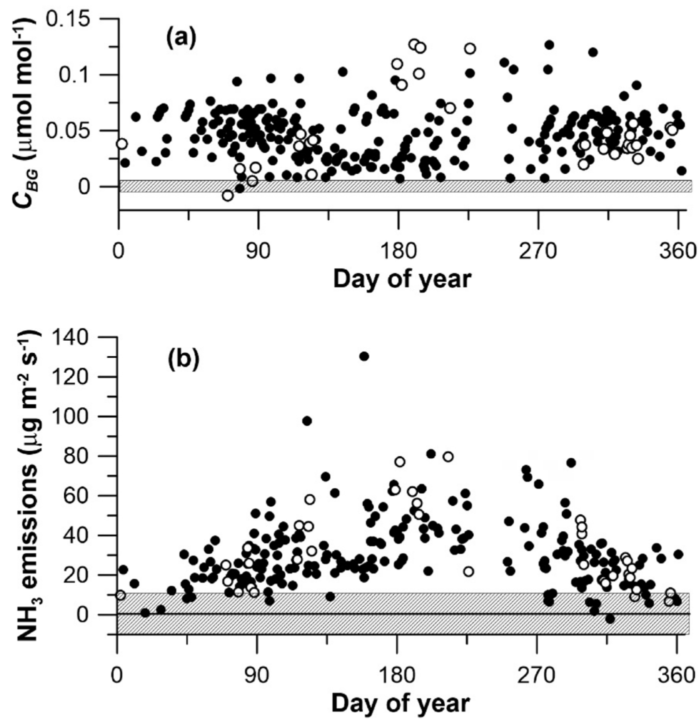


**Figure 1. Annual variation in mean daily emissions and mean $C_{BG}$. Daily mean $C_{BG}$ associated with emissions (a) and mean emissions (b) and for the IN dairy lagoon (filled circles) and WI basins (open circles). Hatched regions represent the +/- median $C_{BG}$ during frozen conditions (a) and emissions minimum detection limit (MDL) (b).[4]**

**Table 1. Seasonal $NH_3$ emissons[4]**

| Farm | Period | NH3 Emissions | | | | |
|---|---|---|---|---|---|---|
| | | Mean g $NH_3$ $s^{-1}$ | SD ‡ g $NH_3$ $s^{-1}$ | Mean µg $NH_3$ $m^{-2}s^{-1}$ | Mean g $NH_3$ hd $^{†-1}d^{-1}$ | Mean g $NH_3$ AU $^{*-1}$ $d^{-1}$ |
| WI | Spring | 0.20 | 0.105 | 28.8 | 31.6 | 24.9 |
| | Summer | 0.42 | 0.137 | 58.7 | 64.3 | 50.6 |
| | Fall | 0.17 | 0.075 | 24.6 | 24.3 | 21.0 |
| | Winter | 0.07 | 0.015 | 9.2 | 10.1 | 8.0 |
| | Annual | 0.21 | | 30.3 | 40.0 | 32.1 |
| | Total | 0.22 | | 31.2 | 33.1 | 26.8 |
| IN | Spring | 0.24 | 0.033 | 28.4 | 8.96 | 6.79 |
| | Summer | 0.39 | 0.039 | 38.2 | 14.2 | 9.27 |
| | Fall | 0.26 | 0.086 | 24.3 | 9.52 | 6.52 |
| | Winter | 0.17 | 0.016 | 17.8 | 5.22 | 4.47 |
| | Annual | 0.26 | | 27.2 | 10.0 | 7.08 |
| | Total | 0.27 | | 30.4 | 9.47 | 6.76 |

‡: SD = standard deviation. *: animal unit (1 AU = 500 kg live mass). †: hd = animal "head".

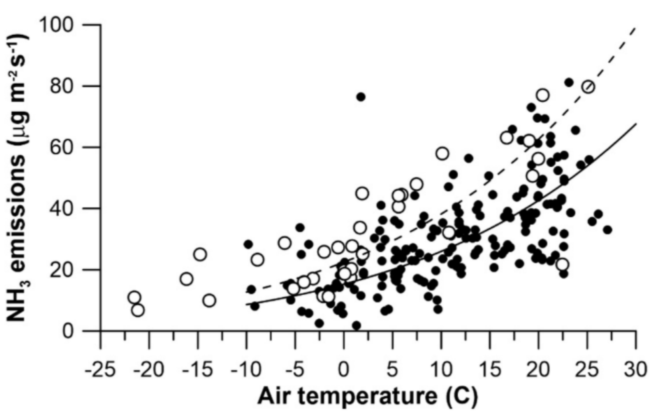


**Figure 2. Influence of air temperature on daily $NH_3$ emissions. The influence of air temperature on daily emissions at the IN (filled circles) and WI (open circles) is indicated. The best regression fit for the IN dairy (solid line) and WI dairy (dashed line) for a given temperature. Three outliers were excluded from IN lagoon emission analysis: one negative and two outlying high-emission measurements (Figure 1).[4]**

**Table 1** shows that the emissions were over six times as great in the summer temperatures as they were in the winter temperatures for the WI farm (50.6 vs. 8.0 g $NH_3$ $AU^{-1}$ $d^{-1}$). The IN farm also showed an increase in emissions for the summer data, but not nearly as significant as the WI farm increase (4.47 vs 9.27 g $NH_3$ $AU^{-1}$ $d^{-1}$). The lower emissions from the IN study most likely resulted from measurements from only a milking parlor and holding area, while the other study included any emissions from waste from barns.[4]

**Figure 2** shows the best regression fit lines for the two different farms and the clear increase of emissions following the increase in air temperature. As days start warming up in the summer months, $NH_3$ emissions are expected to rise. Housing type and manure storage directly relate to this $NH_3$ curve with air temperature. Ventilation and how the livestock move within the structure can also have an effect on this relationship.

## DETECTION METHODS/PROBLEMS

Because $CH_4$ and $NH_3$ emissions can vary based on location, number of livestock, temperature, and housing, it is important to accurately measure the gas emissions for both the safety and health of the livestock and workers. Agriculture is a major source of $NH_3$ emissions, most of which are a result of livestock housing. Many methods have been developed to directly measure emissions from livestock and housing: passive diffusion, sample bags or tubes, chemiluminescence, infrared (IR) spectroscopy, laser absorption spectroscopy, and more.[5]

Passive diffusion relies on the diffusion of gases onto an absorbing medium, moving the gas from an area of high concentration to an area of low concentration containing the absorbing medium.[5] It can be easy to use, low cost, and can show high sensitivity, but it can only be used over long periods of time, gives an average concentration, and the total cost of measurement may be much higher due to repeated measurements over long periods. Sample bags and tubes may sound easy to implement and can preserve the samples for an extended time period before analysis, but they require significant care and protection during transportation and filling. This method is typically used for laboratory measurements and not in-field measurements. Chemiluminescence provides high sensitivity and fast response time, however, it can require frequent calibration and is very expensive for accurate instruments. IR absorption spectroscopy is one of the standard methods used for gas detection. With similar advantages as chemiluminescence, IR absorption spectroscopy can also measure multiple compounds at the same time and can be used where there are high concentration fluctuations. Some of these IR absorption instruments require frequent calibration and can be sensitive to ambient conditions.[5]

Laser absorption spectroscopy combines high sensitivity and precision, fast response time, low risk of interference, and can be easier for non-specialists to operate.[5] One technique includes using a gas absorption cell to achieve a long optical path length for better sensitivity in detection. Although it is extremely accurate and can provide portability to an experiment, it can be problematic when pumping the sample into the cell due to influence from particles and humidity in the air.[1]

For fast analysis of emission concentrations in the air of livestock housing, remote measurement capability is a requirement of the gas detection technology. The gas detection instrument also needs to be small and easy for most workers to use inside the livestock structures. It is critical for the instrument to remove the interference of other gases and measure only the selected or specified harmful gases.

## SOLUTION

Researchers from the School of Electronic Engineering and Automation, Beijing Research Center of Intelligent Equipment for Agriculture, and the Beijing Research Center for Information Technology in Agriculture have developed two different methods of laser absorption spectroscopy for gas emission detection in livestock housing: open path[1] and tunable[2]. Both of these techniques provide high sensitivity and accuracy for $NH_3$ detection and concentration measurements while enabling real-time analysis in the field.

### Open path laser absorption spectroscopy

Open Path Laser Absorption Spectroscopy (OPLAS) eliminates the need for pumping the sample gas into a gas absorption cell for analysis. Although the requirements of the OPLAS system can be higher than others concerning laser spot quality and optical devices, the overall setup can be relatively simple.[1] **Figure 3** shows the OPLAS setup (excluding temperature control and the modulation portion of the laser driver). This setup is comprised of three main sections: the laser driver, laser beam collimation, and the laser signal detection. One of the most important aspects of the system is the laser control for stable laser temperature, output, and accurate wavelength scanning.

With OPLAS, the laser beam will be partially absorbed by any gas in the air. With stable wavelength scanning, absorption spectra can be analyzed with high precision. A photoelectric detector converts the reflected laser signal into a voltage signal to view the absorption spectrum. To test the OPLAS setup, a plastic box is placed in the path of the laser beam in between the mirror and hollow retroreflector. Without any ammonia gas present in the box, the collected voltage signal from the reflected beam contains no absorption peak. However, when the box is filled with a certain concentration of ammonia gas, the voltage signal shows an absorption peak. With this design, detection of ammonia concentration in open spaces is possible, enabling air analysis in livestock and poultry housing.

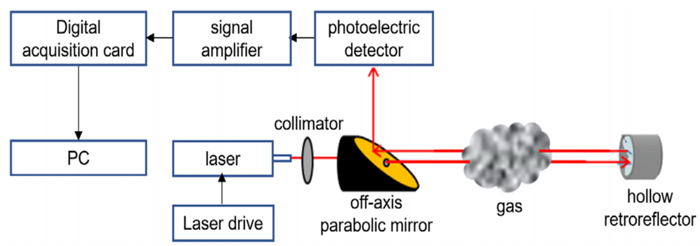


**Figure 3. Principle block diagram of open path laser absorption spectroscopy detection method for harmful gases in livestock and poultry houses.[1]**

A low power distributed feedback (DFB) laser is used with 5 mW output, spectral bandwidth of 0.2 nm, and a central wavelength of 1512 nm. The laser utilizes a butterfly tail fiber type package for cooling with a thermoelectric cooler from a high-precision temperature controller. The fiber tail laser allows simple collimation to focus the laser beam and to control the laser spot diameter and divergence angle for long-distance transmission.[1]

### Tunable diode laser absorption spectroscopy

Similar to the OPLAS, Tunable Diode Laser Absorption Spectroscopy (TDLAS) uses the absorption spectrum of a diode laser to analyze gas concentrations in air. Unlike the OPLAS setup, TDLAS uses a long path gas absorption cell and requires less space. Light is reflected many times in this cell and eventually detected by the photoelectric detector after 48 traversals. The complete TDLAS setup can be seen in **Figure 4**.

Special reflection mirrors are used to produce high transmission quality of the light after multiple passes in the gas cell. These are gold-plated and have a concave surface with high reflectivity and smoothness.[2] The increased path

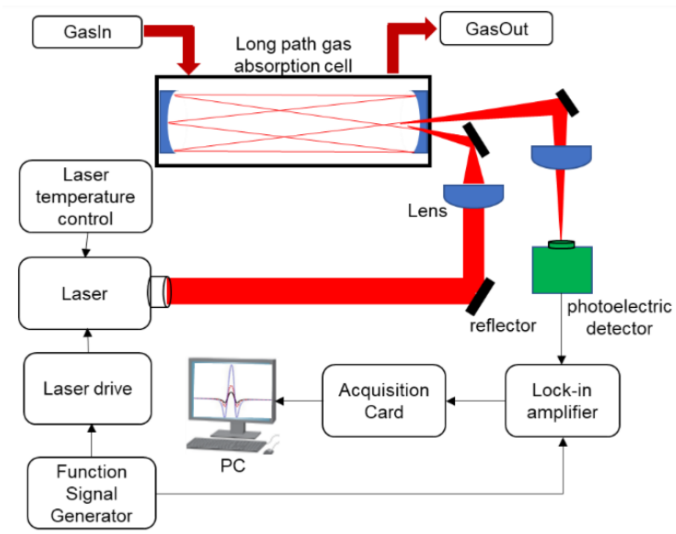


**Figure 4. Principle diagram of high-sensitivity detection of harmful gases in livestock based on TDLAS[2]**

length of the light increases the sensitivity of gas detection due to the Beer-Lambert law which directly relates absorption to path length.

Once again a distributed feedback laser is used at 5 mW output power and a central wavelength of 1512 nm. A butterfly pigtail package is used for precision control of laser temperature using the thermoelectric cooler inside the package. The photoelectric detection circuit is also crucial to the TDLAS technique. One of the most critical pieces, relating to the performance of the signal detection and absorption spectum, is the photodiode. Photodiodes with low temperature drift, minimal dark noise, low junction capacitance, and high responsitivity are necessary for sensitive measurements.[1] Controlling the laser current and temperature for stable tuning and output is also necessary for accurate results.

## RESULTS

Both studies provide a theoretical basis and technical support for emission detection and control in livestock housing. While differing slightly in setup and technique, these spectroscopy methods enable high sensitivity detection of low concentration ammonia and potentially other harmful gases produced in agricultural settings.

The OPLAS setup resulted in an advantageous technique in high dust, high temperature, and high humidity environments without the need for a gas absorption cell. The length between the collimator and retroreflector was 2 m, making the total path length traveled by the light 4 m. The laser diode was scanned and modulated between the current range of 55 - 85 mA using a 5 Hz low frequency sawtooth wave. Experiments in the study showed that the OPLAS detection system can detect the voltage absorption peak caused by ammonia absorption of the laser beam within the 4 m open path with extremely high sensitivity.[2]

The TDLAS setup did not allow for direct absorption signal detection in the gas absorption cell. However, the harmonic absorption signal can be recorded by an oscilloscope. This type of detection enables more sensitive and accurate results compared to direct absorption signal detection. The equipment and the ammonia detection can be seen in **Figure 5** below. The direct absorption signal follows the laser driver signal without any absorption peak or events. The harmonic absorption signal shows an absorption peak at a certain wavelength along the current scanning ramp.

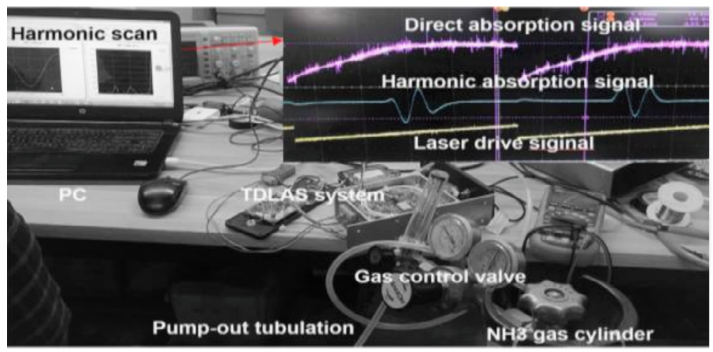


**Figure 5. Real equipment photo of ammonia detection based on TDLAS with long light path.[2]**

The laser wavelength was scanned and tuned using a 5 Hz low frequency sawtooth wave and a 5 kHz frequency modulation sinusoidal signal input through the laser driver. This experiment proved the usefulness of tunable lasers in ammonia gas detection in livestock housing and similar applications. The system recorded detecting harmonic signals created by ammonia with a concentration of lower than 5 ppm, showing high sensitivity for livestock environments.

This sensitivity allows the detection of low levels of ammonia, which start to affect livestock and human workers at concentrations of 10 - 30 ppm. The TDLAS technique enables precise detection of ammonia before affects can be severe and harmful around 50 ppm.

Future research and experiments will further prove the effectiveness of OPLAS and TDLAS and other types of laser absorption spectroscopy in the field of agriculture. Better detection of $NH_3$ and other harmful gases could lead the way for safer and healthier environments for livestock and poultry. These, along with assessments of housing types, ventilation systems, and flooring types, can enable accurate support for intelligent air quality detection and control in livestock and poultry housing.

## WAVELENGTH'S ROLE

Since laser absorption spectroscopy requires high precision and accuracy, the electronics driving the system need to have high performance capabilities. Wavelength Electronics' laser drivers and temperature controllers enable the sensitive measurements and analysis for ammonia gas detection in livestock housing.

Laser stability is critical for sensing low concentrations of harmful gases in the air. Wavelength's low noise laser diode driver, the WLD3343, can precisely deliver 500 mA of current to the laser diode without any heat dissipation accessories required, shown in **Figure 6** (red component on left side). This driver can supply up to 3 A of current and has the convenient option for voltage-controlled setpoint to further protect the laser. Because each study used some form of modulation, the initial sinusoidal or sawtooth signal was sent to the laser driver to modulate the output current to the laser, simplifying steps. The driver enabled easy and precise scanning of the wavelength through the modulation of the supplied current. The WLD3343 laser diode driver can also be seen with a heatsink in **Figure 7** on the left side.

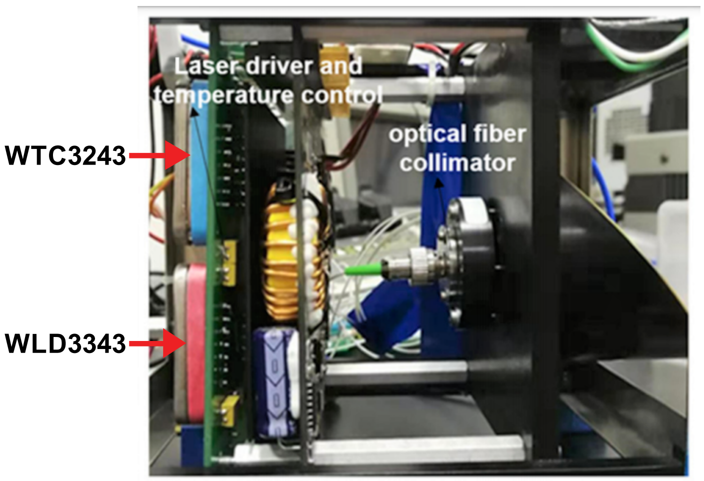


**Figure 6. Open path laser absorption spectroscopy gas detection system: assembly physical diagram.**[1]

For stable output power and accurate wavelength scanning with repeatable results, researchers used Wavelength Electronics' WTC3243 temperature controller to control the laser temperature with stability better than 0.0009ºC. The benefits of the temperature controller can also help narrow linewidth and can ensure stable wavelength. The laser diode's life and performance are improved by tighter and more precise control of the laser heatsink temperature.

The WTC3243, shown in **Figure 6** (blue component on left side) and in **Figure 7** (bottom right underneath fan), can drive ±2.2 A of current to a thermoelectric with both heating and cooling current limits. The PI control loop offers maximum stability while maintaining efficiency.

WLD3343 WTC3243

**Figure 7. Laser wavelength scanning system.**[2]

Laser safety features include slow start, current limit, and over temperature output shutdown from a signal from the temperature controller. The small and compact design of the WTC3243 and the WLD3343 of 1.3 x 1.28 x 0.313" allows operation in other handheld or portable equipment similar to the ammonia detection in livestock housing.

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## USEFUL LINKS

- WLD3343 Product Page
- WTC3243 Product Page

| PRODUCTS USED |
|---|
| WLD3343, WTC3243 |

| KEYWORDS |
|---|
| Livestock, laser diode, spectroscopy, laser absorption spectroscopy, tunable wavelength, ammonia, methane, emissions, open path, gas detection, farming, housing systems, temperature, laser driver, temperature controller |

## PERMISSIONS



**REVISION HISTORY**

Document Number: CS-LDTC09

| REVISION | DATE | NOTES |
|---|---|---|
| A | June 2021 | Initial Release |