Highly Selective Optical Fibre Ammonia Sensor for use in Agriculture

G. Dooly, H. Manap, S. O’Keeffe, E. Lewis
Optical Fibre Sensors Research Centre, University of Limerick, Ireland.

Abstract
A highly selective optical fibre sensor has been developed for the monitoring of low level atmospheric ammonia concentrations. The measuring technique employed is based on a differential optical absorption approach, which uses a broadband optical source, optical fibres for transmission and a miniature ultraviolet/visible spectrometer for detection. This novel technique for the detection of ammonia has previously been shown to be capable of monitoring concentrations as low as 1ppm without any notable cross-sensitivity issues [1]. The sensor was operated over a number of hours in-situ in an agricultural cattle enclosure and simultaneously with a commercially available ammonia sensor. Results shown herein demonstrate the effectiveness of the developed sensor to operate within the environment accurately, recording concentration levels of between 0 and 2 ppm.

1. Introduction
The detection and monitoring of ammonia gas has become an important topic in recent years, particularly ammonia naturally produced through livestock farming [2]. Exposure to excessive levels of ammonia gas within an agricultural environment can lead to a whole range of health issues, both for animals and agricultural personnel alike. The use of an accurate ammonia sensor can alert personnel to dangerous levels of ammonia in the atmosphere and may prevent serious health damage or even death.

Once ammonia emissions enter the earth’s atmosphere they can lead to many adverse environmental affects including acidification and ground-level ozone. As a result, increasingly stringent European legislation such as the National Emissions Ceilings (NEC) Directive has been established in an effort to reduce the amount of ammonia emissions worldwide [3]. This renewed interest resulting from European legislation over the last number of years has also led to an increase in demand for a sensitive sensor capable of monitoring low levels of ammonia gas within an agricultural environment.

* Corresponding Author: G. Dooly. E-mail address: gerard.dooly@ul.ie; Tel.: +35361 21 3386; fax: +353 61 33 8176.
2. Existing Technologies

Commercially available sensors are generally based on semiconductor technologies; however these sensors often have a low lifespan due to the inherent structure of their sensing technique [3]. Although sensors based on this technique can provide a relatively high level of sensitivity, they usually suffer from a significantly low level of selectivity. This can be of significant importance when monitoring ammonia gas within an agricultural setting. The surrounding atmosphere in an agricultural setting comprises primarily of nitrogen, oxygen, carbon dioxide and water vapour. However, many other species exist in lower quantities. This wide composition makes it difficult for sensors based on semiconductor technologies to operate effectively within such an environment. This is due to their inherently low level of selectivity which can result in significantly high levels of cross-sensitivity and ultimately false readings.

Sensors based on optical absorption can offer a much more selective and robust system, which is suited to low level harsh environment monitoring such as that present in an agricultural setting. Recently developed optical devices operating within the ultraviolet region of the spectrum has allowed for the development of low cost optical based sensors within this region. This has allowed for a low cost optical approach based on absorption in the ultraviolet region. This technique, often referred to as differential optical absorption spectroscopy, allows for a significantly high selectivity response through the monitoring of absorption lines associated with ammonia gas molecules between 171nm and 216nm (reported previously by Chen et al) [4]. Through the analysis of similarly reported absorption coefficients for nitrogen, oxygen, carbon dioxide and water vapor, shown in fig. 1 (a), it was determined that cross-sensitivity effects within this region were negligible.

Ammonia sensors have also been reported based on optical absorption within the Infrared region [5]. However due to relatively high absorption strengths for water vapor in this region, these sensors can exhibit cross-sensitivity to humidity.

3. Calibration

An extrinsic sensor based on an open path configuration is the basis for the sensor setup described herein. The setup consists of a deuterium–halogen lamp (DH-2000 from Ocean Optics) for optical light emission and a high resolution spectrometer (Ocean Optics HR2000) for optical detection. Collimating lenses are located at either end of the gas cell to aid with the propagation of optical light across the open space, where it interacts and absorbs parts of the optical light. Optical fibres for transmission to the sensing region allow for remote monitoring and online measurements, giving the possibility for data analysis on optical light recordings in real-time. The experimental setup for the sensor is shown in fig. 1 (b).

![Fig. 1. (a) Theoretical and measured absorption line intensities for NH3; (b) Experimental setup](image-url)
Extensive laboratory based experimental tests were carried out in order to effectively calibrate the sensing system and also to quantify the ability of the system itself [1,6]. Laboratory based experimental tests shown in fig. 2 demonstrate the sensor’s ability to monitor concentrations as low as 1ppm, without any significant cross sensitivity issues to other atmospheric gases.

Fig. 2. Recorded concentration levels for varying amounts of NH3

4. In-Situ Experimental Tests

In-situ experimental tests were required to assess and fully quantify the performance of the optical sensor within the required environment. These experimental tests were carried out in an agricultural cattle enclosure in the Republic of Ireland, with 22 cattle accommodated across four fenced sections. The experiments were carried out during the peak winter season where ammonia is believed to be existing at a very low concentration [8]. The weather was foggy with some snow and the temperature was recorded at 0°C.

The optical sensor was placed at one corner of the enclosure, approximately 3m from the fenced section where a group of cattle was located. A cylinder of nitrogen gas was used in order to flush the absorption cell prior to the experimental test, while a vacuum pump was used to pump the surrounding air into the cell during the testing procedure. The experimental test results are shown in figure 5.

Fig. 3. Recorded concentration levels for varying amounts of NH3
To begin the in-situ experimental test, the nitrogen gas was turned off and pump was initiated. Although concentration levels recorded by the optical sensor are significantly low, approximately 1ppm, the sensor is able to accurately determine the presence of ammonia in the surrounding atmosphere. Following a period of approximately 10 minutes, the pump was turned off and the absorption cell is flushed with nitrogen. Once this occurs, the concentration readings from the optical sensor quickly return to zero. Upon the initiation of the pump (and deactivation of nitrogen) for the second time, the sensor once again records a concentration of approximately 1ppm, demonstrating a strong level of repeatability. Although the commercial sensor was operated throughout the testing procedure, it did not record any concentration levels of ammonia, indicating that it was incapable of measuring such low concentrations.

5. Conclusions

To overcome cross-sensitivity issues usually evident within commercially available ammonia sensors an optical approach was undertaken. A technique based on differential optical absorption spectroscopy was employed as it offered a relatively low cost solution with a high level of sensitivity. Experimental tests were carried out using varying concentrations of ammonia as well as other atmospheric gases. Further tests were carried out in-situ within an agricultural cattle enclosure in the republic of Ireland in conjunction with a commercially available ammonia sensor. Results shown herein demonstrate a lower limit of detection of at least 1 ppm, response times under 4s and no recordable cross-sensitivity issues.

References