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AN OPEN-PATH OPTICAL FIBRE SENSOR FOR AMMONIA MEASUREMENT IN THE ULTRA VIOLET REGION

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ABSTRACT

This paper describes an optical fibre sensor system for displaying of ammonia gas spectrum. An open path optical technique is used to analyze the absorption lines of ammonia within the Ultra Violet Region. Experimental results describing the operation of the sensor with varying gas concentrations are presented and are compared with recorded results calculated from measured experimental flow rates. The results show the sensor is capable of detecting small concentration changes of ammonia.

Keywords: fibre optics, ammonia, sensor, ultra violet.

INTRODUCTION

Ammonia gas is toxic to both human and animal life alike and its maximum safe level is 25 ppm for long term exposure (8 hour) and 35 ppm for short term exposure (15 min) [1]. According to the European Environment Agency, (EEA) report Jan 2014, ammonia (NH_3) emissions is primarily contributed by the agricultural sector. Only minimal amounts of ammonia emissions derived from other sectors such as industrial processes and road transport.

The concentration level of ammonia in an enclosed agricultural environment such as a milking parlour is of high importance, both in relation to the health of the livestock and also the agricultural personnel. In addition to this safety concern, increasingly stringent European legislation such as the National Emissions Ceilings (NEC) Directive has set a high demand for a sensitive and selective ammonia sensor. The NEC directive has set a target of certain amount of NH_3 emissions in all European countries as shown in Figure-1.

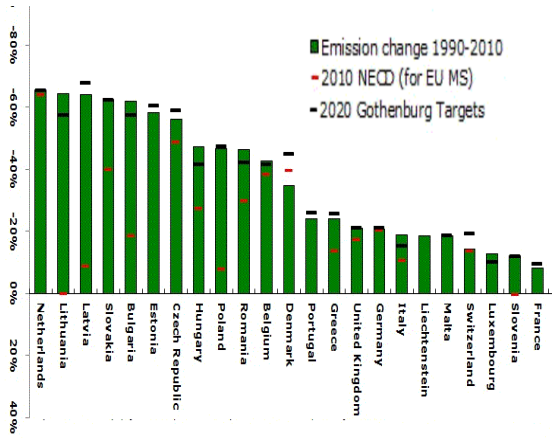

Figure-1. Trends in NH_3 emissions (Source: EPA).

There are many types of ammonia sensors which have their own advantages and disadvantages and have been discussed in details in [2]. However it has also been discussed [3] that relative humidity has always been a constraint in ammonia testing because of cross sensitivity. This is particularly true in sensors based on solid state devices such as semiconductors.

Barber *et al* [3] have mentioned that UV absorption is merely affected by water content, which makes this sensor in UV range plausible for operation within moisture-saturated samples. In addition, an optical fibre based gas sensor can have many advantages in terms of low weight and small size [4], resistance to high temperature [4,5], no electromagnetic interference, and can have distributed measurement rather than a point sensor [6]. Also, in previously [7] it has been shown that the absorption spectrum for water in the UV range exists between 183 nm to 193 nm. Hence, there should be no cross sensitivity issues with water content since ammonia absorption lines in this work have occurred between 200 nm to 225 nm.

THEORY

Different gas species absorb light at different characteristic wavelengths and for ammonia gas, it has its own specific gas spectrum. A comprehensive collection of absorption cross sections for gaseous molecules can be accessed from the MPI Mainz database including ammonia gas.[8] The data varies from source to source and they depend on temperature and wavelength range. Only one that suits with experimental condition parameter was selected and compared with the measured results. The data for NH_3 from the MPI Mainz database was taken as the theoretical spectrum for NH_3 gas and is shown in Figure-2 below.

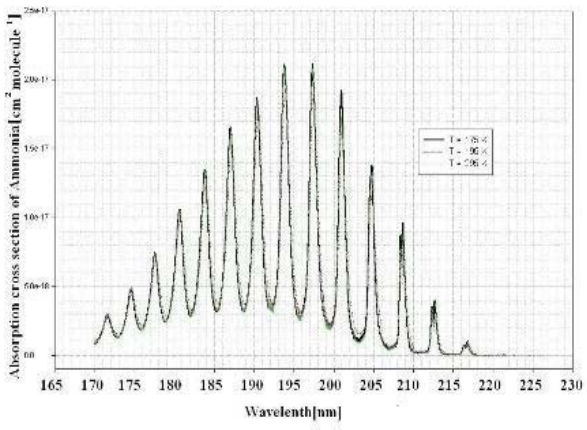

Figure-2. Ammonia spectrum, Chen *et al*, planet space Sci. 47 (1999) 261.

For ammonia gas concentration calculation, the Beer-Lambert Law can been utilised. The **Beer-Lambert law** described the relationship between absorbance and concentration of an absorbing species and its general form is shown in equation (1).

$$\frac{I}{I_o} = e^{(-\varepsilon c l)} \quad (1)$$

Where I is the transmitted intensity, I_o is the incident intensity, l is the distance that the light travels through the gas, c is the concentration of the gas, and ε is the absorption coefficient of the species.

In order to calculate the gas concentration, c in parts per million, ppm, a variation of Beer Lambert Law was used as shown in equation (2) and (3) as follows;

$$\varepsilon = \sigma \times N_A \quad (2)$$

$$c = \frac{ppm}{\omega \times d \times 10^6} \quad (3)$$

where σ (cm^2/Molecule) is the absorption line intensity, ω(amu) is the atom molecular unit of the species, (kg/m^3) is the density of the species, and N_A is Avogadro's constant. Replacing equation (2) and (3) into (1) gives

$$\frac{I}{I_o} = e^{-(\frac{\sigma \times N_A \times ppm \times l}{\omega \times d \times 10^6})} \quad (4)$$

Hence

$$ppm = \frac{-[\ln \frac{I}{I_o}][\omega \times d \times 10^6]}{\sigma \times N_A \times l} \quad (5)$$

Using equation (5), we can accurately calculate the gas concentration with all parameters known. As we can see all the parameters can be assessed in real time. Therefore we can have the concentration reading in real time if we develop a program that can access all those parameters. This method of gas concentration calculation was described previously in [9-11].

Theoretical gas concentrations can give a strong comparison to measured concentrations from the sensing system and are usually referred to in the development of The theoretical gas concentrations can be calculated if the flow rate of the gas is known during the testing stages. The method of concentration calculation from the flow rate is shown below;

$$NH_3(ppm) = \frac{\%NH_3}{\%NH_3 + \%N_2} \times 10{,}000\, ppm \quad (6)$$

where

$$\%NH_3 = 0.77A \quad (7)$$

$$\%N_2 = 0.98B \quad (8)$$

where A and B are flow rate in l/min for NH_3 and N_2 respectively. The number 0.77 and 0.98 are the gas conversion factor for NH_3 and N_2 respectively. These numbers vary depending on the gas condition and controllers used in the experimental setup.

EXPERIMENTAL SETUP

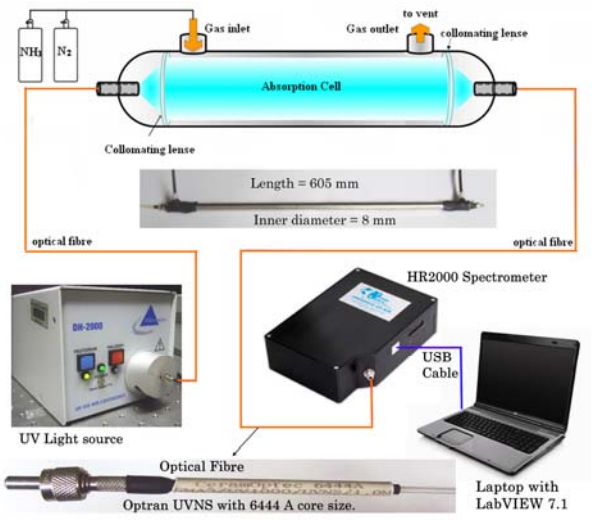

Figure-3. Experimental setup.

The experimental arrangement is shown in Figure-3 above. A Deuterium-Halogen lamp (DH-2000 from Ocean Optics) was used as a light source. The light was transmitted through a fibre (Optran UVNS, Ultra Violet Non Solarising) with 6444 A core size. Two collimating lens were placed at both ends of the gas cell

and were used to focus the incident and transmitted light. The transmitted light was then travel through another optical fibre at the other end of the test gas cell to the light detector. The light detector that was used in this experiment was an Ocean Optics HR2000 spectrometer. The spectrometer has a range from 200 to 650 nm and it provides resolution to 0.65 nm (FWHM). The spectrometer was connected to the computer with LabVIEW 7.1 software installed. A specifically designed program was developed in LabVIEW in order to control data acquisition from the spectrometer and also perform all data processing so that the concentration of the analysed gas present can be output to the user in real time.

RESULTS AND ANALYSIS

Initially, 25 l/min of nitrogen and 0.1 l/min of 100% ammonia gas were released into the test gas cell. Based on the flow rate released, the concentration of ammonia can be calculated and it was found that 3133 ppm of ammonia that was present in the test gas cell. The spectrum of the ammonia gas was recorded and the graph was plotted and compared with the theory as shown in Figure-4.

Although the measured spectrum is similar to the theoretical spectrum, clearly some error exists. This could be due to inaccuracies in the measured calculations due to errors in gas flow measurement or it due to inaccuracies in the theoretical.

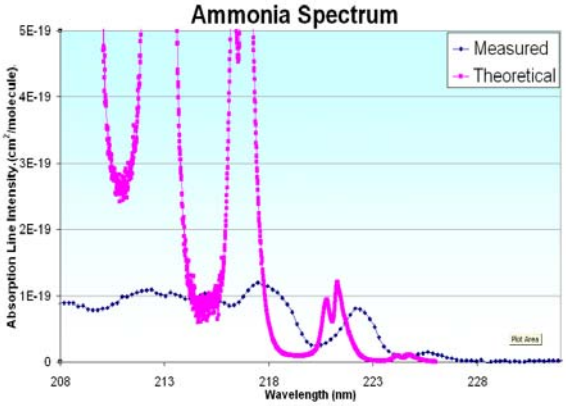

Figure-4. Ammonia spectrum comparison.

An addition experimental test was carried out, recording the varying concentrations of ammonia present over an extended period of time. Initially the gas cell was flushed with nitrogen to start a new experiment. This time, the absorption for different ammonia concentration was tested. Firstly, 0.1 l/min of ammonia and 20 l/min of nitrogen was released using gas regulators. This was followed by 21, 22, 23, 24 and 25 l/min of nitrogen in order to dilute the ammonia gas concentration. Then other mixed combination of ammonia gas and nitrogen was released as shown in the Table-1.

Table-1. Ammonia and nitrogen flow rate.

NH_3 (l/min)	N_2 (l/min)
0.1	20
0.1	21
0.1	22
0.1	23
0.1	24
0.1	25
0.0	23
0.1	23
0.1	20

The concentration data was recorded during the test cycle by the LabVIEW program and was not only displayed to the user during testing but was also output to the PC at the end of the cycle. The measured flow rates were used to formulate the theoretical gas concentration over the test cycle using equation 6.

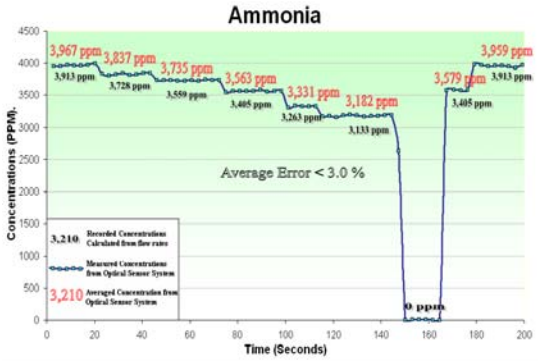

Figure-5. Absorption levels for different ammonia concentration.

Figure-5 shows the resulting comparison between the theoretical and measured results. There were seven concentration steps recorded during the test cycle as shown on the graph. It can be seen that averaged concentrations from the sensor closely match theoretical concentrations. This shows that the sensor is capable of accurately monitoring the concentrations of ammonia over time. The lowest step change from the previous experiment is shown to be in the order of 102 ppm however the lower detectable limit for the sensor can be calculated to be close to 7 ppm (signal to noise ratio of 1:1)

CONCLUSIONS AND FUTURE WORK

A novel optical fibre sensor for NH_3 gas has been described and reported. The optical sensor for ammonia shows very promising results and is very close to the theoretical spectrum. The sensor is capable of detecting varying concentrations of ammonia gas and is also capable of outputting this data in real time.

Future work will include the integration of a commercial NH_3 sensor as a more accurate and efficient verification of NH_3 gas concentration. A Mass Flow Controller will also be used to mix the gas with nitrogen in order to get the lowest concentration that the sensor is capable. Finally a full set of experimental tests along with in-situ experiments will be carried out in order to fully quantify the sensing system.

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