Sensitivity and Response Time of an Ozone Sensor

Michael David, Tay Ching En Marcus, Maslina Yaacob, Mohd Rashidi Salim Mohd Haniff Ibrahim, Sevia Mahdaliza Idrus, Asrul IzamAzmi, and Nor Hafizah Ngajikin

***Abstract*—The use of optical retro-reflectors in improving the sensitivity and response time of an optical sensor based on optical absorption spectroscopy for the measurement of ozone gas is presented. Two optical retro-reflectors are employed in the design of a 30cm and 20 cm absorption gas cells. Our analysis shows that, in the 30cm gas cell, a sensitivity of 0.0451ppm and 0.0901ppm is achievable while in the 20cm gas cell we can achieve a sensitivity value of 0.0681ppm. However these sensitivity values are dependent on the optical density of the sensor. In general gas cell with wider diameters has potentials for a faster response time.**

***Index Terms*—Monitoring, Optical path length, Optical recto-reflectors, ozone, sensitivity, response time, gas cell diameter.**

I. Introduction

Increasingly, more research activities have been devoted towards the sensing and monitoring of gases that constitute hazard to the wellbeing of humanity [1]. Ozone, a toxic gas has a wide range of industrial applications such as: air treatment, biomaterial cleaning and sterilization, water supplies and contaminants sterilization, bleaching and deodorization [2, 3, 4]; ozone has been adopted for the treatment of swimming pool water and a suitable alternative to replace traditional sanitizing agents; it has been approved as an antimicrobial agent to foods [5, 6, 7, 8, 9, 10, 11]. However, exposure to unsafe level of ozone is associated with inherent health dangers such as allergy, asthma, breathing difficulty, inflammations, premature ageing of the lungs, and irritations in the human body; and as a by product of the drying process in a printing press it can result to cancer and heart and blood related diseases, [12, 13, 14, 15, 16].

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Michael David is a PhD student with Light wave Communication Research Group, Infocomm Research Alliance, Universiti Teknologi Malaysia, (email: mdavid2@live.utm.my).

Tay Ching En Marcus is a Phd student with the Light wave Communication Research Group, Infocomm Research Alliance, Universiti Teknologi Malaysia, (email: marcus2412@hotmail.com).

Maslina Yaacob is a PhD student with Light wave Communication Research Group, Infocomm Research Alliance, Universiti Teknologi Malaysia, (email: mas_lina2003@yahoo.com).

Mohd Rashidi Salim is a Phd student with the Light wave Communication Research Group, Infocomm Research Alliance, Universiti Teknologi Malaysia, (rashidi@fke.utm.my).

Mohd Haniff Ibrahim is currently an Associate Professor with the, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, (hanif@fke.utm.my).

Sevia Mahdaliza Idrus is an Associate Professor with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, (sevia@fke.utm.my).

Asrul IzamAzmi is a Senior Lecturer with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, (asrul@fke.utm.my).

Nor Hafizah Ngajikin a Senior Lecturer with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, (nhafizah@fke.utm.my).

II. ABSORPTION OF LIGHT BY OZONE

The monitoring of ozone using optical absorption spectroscopy has been in use and is widely accepted [17]. Ozone absorbs light in the Hartley band, the Huggins band, Chappius band, and the Wulf band. It has peak absorption at 253.7nm and 603nm [18] as shown in Fig. 1.

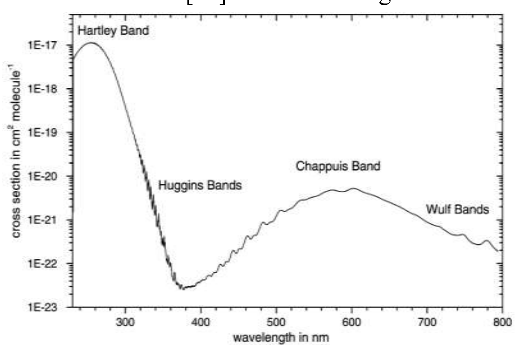

Fig. 1. Ozone spectrum at room temperature [19]

III. BEER LAMBERTS LAW

The working principle of gas cells of the optical gas sensor is based on Beer Lamberts law which states that if radiation of intensity I_0 is directed at an analyte of path length L, radiation of intensity I_t leaves the analyte [20]. It mathematically stated as:

$$I_0(\lambda) = I_t(\lambda)10^{\varepsilon(t,p,\lambda)LC} \quad [21, 22] \qquad (1)$$

Where,

- ε = the decadic molar absorption coefficient of the sample being measured
- c = the concentration of the sample.

By increasing ε and/or L the absorptionmetry can be very sensitive [21].

IV. SENSOR SENSITIVITY

Reference [23] demonstrated the preference for the use of gas cells with long optical paths in comparison to heating an absorption cell to increase heat for the measurements of the spectrums of vapours. Three different concave mirrors (spherical in shape) with the same radius of curvature were combined together in his gas cell to achieve increase in optical length. In recent times, [24 & 25] used optical retro-reflectors to improve detection sensitivity in measuring ozone and observed the need to further improve their design to both improve on sensor sensitivity and response time. The sensitivity (S_s) of a sensor is the smallest amount of analyte (O_3) concentration (i.e. minimum detectable limit) which it is built to measure that it can measure.

Referring to (1), we make C the subject of the equation as shown below:

$$C = \left(\frac{1}{\varepsilon(t,p,\lambda)L}\right)\ \log_{10}\left(\frac{I_0}{I_t}\right)$$

$$C = \left(\frac{1}{\varepsilon(t,p,\lambda)L}\right) D$$

Where D is the optical density

$$C = \left(\frac{D}{\varepsilon(t,p,\lambda)L}\right) \qquad (2)$$

By increasing the value of the denominator of equation (2), the value of the analyte concentration measured reduces and hence increasing the sensitivity of sensor. i.e.:

Increasing the value of $\varepsilon(t,p,\lambda)$*; and/or*
Increasing the value of L;
Reduces the value of C and these results in the increase of Sensor sensitivity (S_s).

V. SENSOR RESPONSE TIME

The response of a sensor is a function of the velocity or rate of diffusion of gas, density of gas, length and volume of gas cell [26], operating temperature and pressure and other related factors. Sensor response time in this design is enhanced by increasing the diameter of the gas cell; since the gas particles diffuse faster in a wider opening than in smaller one. Hence the reason for the use of two retro-reflectors.

VI. NEW SENSOR DESIGN

The design objective of our proposed sensor is sensitivity and response time; since optical sensors in general offer an appreciable response time, our design improves on optical designs where sensitivity and response time needs further improvement [27] . The proposed sensor is based purely on the light propagation principle in an optical retro-reflector.

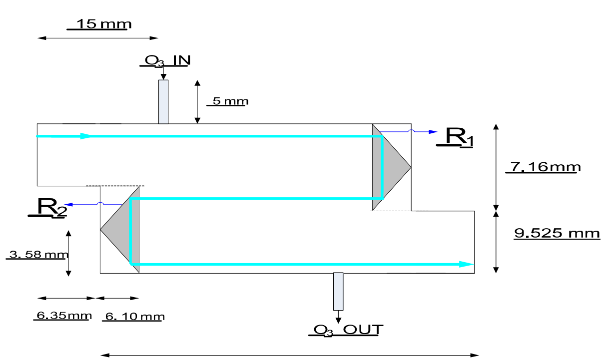

Fig. 2a. Proposed ozone gas cell with two optical recto-reflectors.

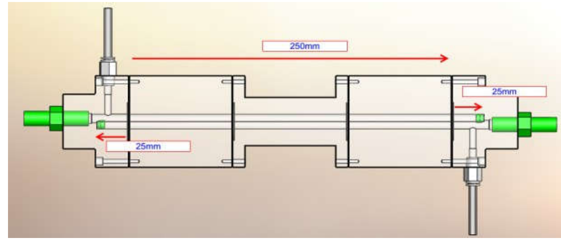

Fig. 2b. Proposed ozone gas cell showing how gas cell is aligned to two optical recto-reflectors.

An optical retro-reflector has three internal surfaces; light incident at 90° is reflected by the three surfaces and reflected light returns parallel to the incident light [28]. Our gas cell aligns two retro-reflectors R_1 and R_2 as shown in Fig. 2a & b.

UV light from Ocean Optics DH-2000 light source is to be incident on R_1 using a launching solarization resistant fiber. The incident light is propagated internally inside the gas cell by the two optical retro-reflectors and interacts also simultaneously with the analyte. The reflected light exits the gas cell by means of a collecting solarization resistant fiber and is to be channeled to an ocean optics spectrometer. The signal from the spectrometer is analyzed on a computer using LabVIEW software.

VII. RESULTS AND DISCUSSION

In the analysis below, three different scenarios are presented: Fig.3 is when the optical densities of our proposed gas cell and a 40cm gas cell with only a single optical retro-reflector are both equal;

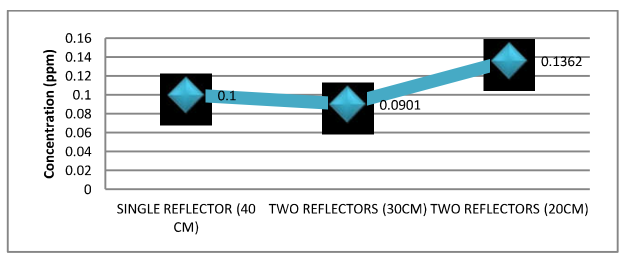

Fig. 3: Analyte concentrations compared with equal values of optical densities.

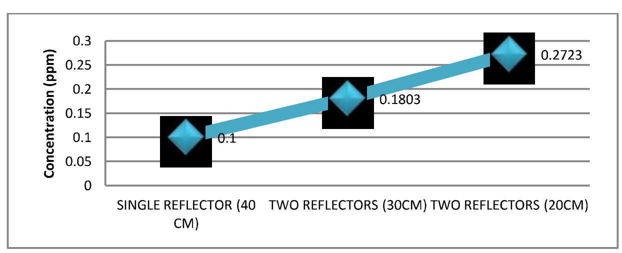

Fig. 4. Analyte concentrations at higher values of optical densities.

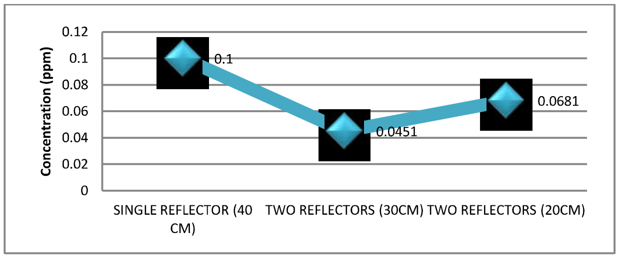

Fig. 5. Analyte concentrations at lower values of optical densities.

Fig. 4 is when the optical density of our proposed gas cell is twice that of the 40cm gas cell and Fig. 5 is when the optical density of our proposed gas cell is half the value of that of the 40cm gas cell.

In our design with two optical retro reflectors in a 30cm and 20cm gas cells, optical path length of 88.755cm and 73.755 cm (approximately) respectively is achieveable; and a sensitivity of 0.0901ppm, 0.01803ppm, and 0.0451ppm for the 30 cm gas cell and 0.1362 ppm, 0.2723 ppm and 0.0681 ppm for the 20 cm gas cell in the first, second and third scenarios.

VIII. CONCLUSION

The Use of N-numbers of optical retro-reflectors the optical path length of an optical gas sensor can be greatly increased and thus increasing sensitivity (minimum detectable limit) which is directly proportional to the overall volume of the gas cell. The response time for our design is enhance as the internal diameter of the gas is increased.

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