The Potential Development of Oxygen Optical Fibre Gas Sensor for Automotive Industry

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***Abstract*— This paper describes the potential future development of an optical fibre based sensor for oxygen detection in the UV region between 200-230 nm. An open-path optical method is used to analyze the absorption lines of the oxygen in the UV region. Experimental result describing the operation of the sensor is presented. A comparison between theoretical and experimental results has been carried out and reported.**

***Index Terms*— Optical Sensor; Open Path; Oxygen Sensor; Oxygen Spectrum.**

I. Introduction

Oxygen is one of the most important gases in creature's life. According to National Oceanic and Atmospheric Administration (NOAA), the concentration of the oxygen in the atmosphere is close to value of 20.9476% (US Standard Atmosphere) [1]. The monitoring systems for oxygen gases are widely demanded in various applications such as for the chemical processes, atmospheric monitoring and automotive industry. To satisfy the demand, many methods and techniques have been explored and developed by the researchers.

The conventional sensor used for oxygen detection is based on colorimetric [2], semiconductor [3], catalyst combustion [4-7], and electrochemical sensor [8-10]. The major weakness of colorimetric method is slower response reversibility, harder to reset the detector quickly and cannot measure instantaneous oxygen levels [11]. Semiconductor type sensor has several weaknesses such as high input power, lower resolution, higher temperature and humidity dependence, difficult to achieve sensitivity, selectivity and specificity in presence of mixture gases [11-12]. Catalyst-combustion and electrochemical sensors particularly have lower humidity and temperature dependence, lack of long-term sensitivity and tend to suffer from possible cross-contamination or poisoning effects of some gases and vapor [11].

The oxygen sensor is also reported and developed previously by using different technology such as MEMs [13-15] and MOS sensor [16-18] which have their own disadvantage. One of the main disadvantages is that they are not selective to single gas detection alone.

There are various types of oxygen sensor [19-23] were developed for applications in industry and research, but the oxygen optical fibre sensor is more applicable for the automotive industry due to its immune to high temperature [24], fast response, no electromagnetic interference and can be easily measured in mixed gases content [25].

Therefore, it can be a great alternative to conventional sensors when an optical fibre oxygen sensor that is selective to single gas detection, immune to high temperature, fast response, no electromagnetic interference and can be easily measured in mixed gases content was developed. It can be a great alternative to the conventional sensors. In this paper, the absorption spectrum of the oxygen gas is measured in the UV region and the spectra are compared with the theoretical data from UV Mainz Spectral Atlas of Gaseous Molecules from Max Plank Institute.

II. Theory

Every different gas species absorbs light at a different wavelength. Therefore, it gives the gas its own special absorption characteristic and for oxygen gas, it has its own absorption line. Figure 1 below shows an absorption cross-section line of oxygen gas recorded by many researchers since 1971. As it can be seen from Figure 1, the line for oxygen varies and the rate of absorption is different. However, the curve is almost similar where the rate of absorption is descending from 200 nm to 230 nm. This is common due to too many factors such as different light source and detector used. Temperature difference will also affect the rate of absorption.

Based on Figure 1, it can be seen that the theoretical absorption cross section of oxygen gas absorbs light within the wavelength range of 195 nm to 235 nm. However, the absorption study for this oxygen gas is restricted to 200 *nm* – 230 *nm* wavelength range as the gas absorption spectrum has a decent absorption at this range. Hence, there is some potential point will be selected for detection of oxygen gas in the UV region for this optical fibre sensor development. Therefore, the cross sensitivity studies must focus on this wavelength range of (200 *nm* – 230 *nm*) for any gas interference observation and testing. It is important to determine absorption wavelength to avoid any cross-sensitivity issue with surrounding gases existing within the vehicle exhaust.

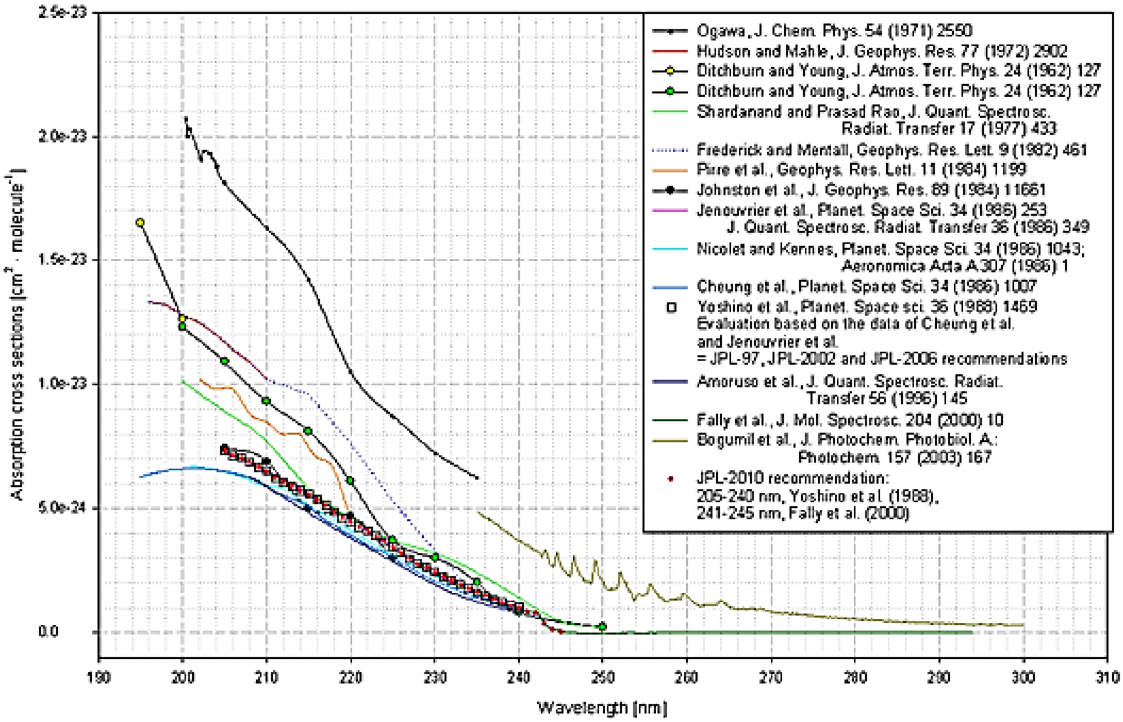

Figure 1: Theoretical data of oxygen absorption spectrum ("The MPI-Mainz UV/VIS Spectral Atlas of Gaseous Molecules of Atmospheric Interest")

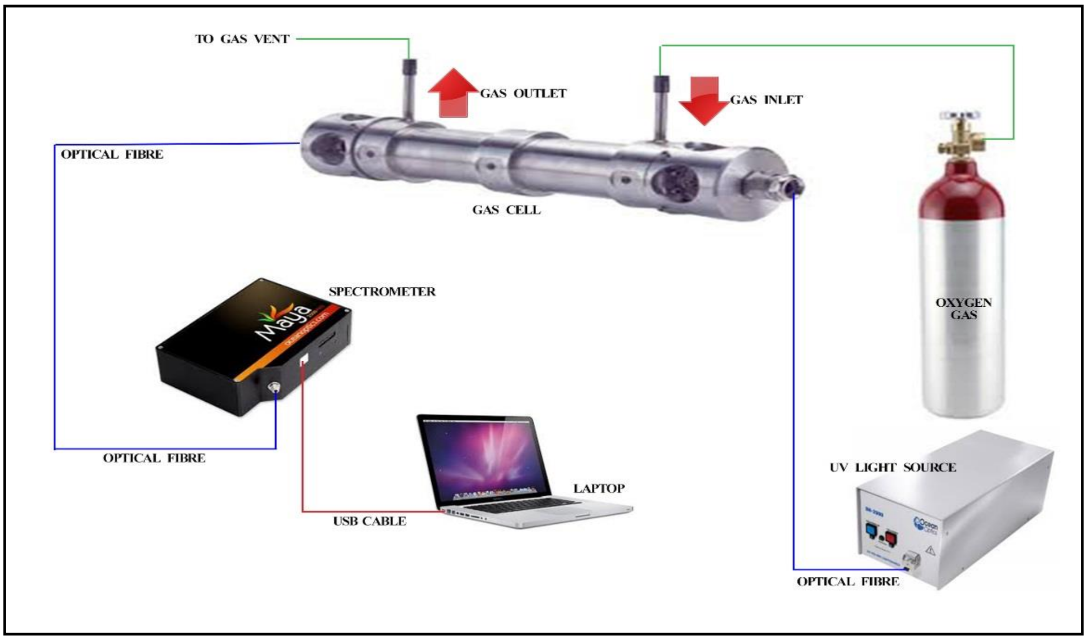

Figure 2: Generic design of Oxygen Detection System

III. Experimental Arrangement

A generic design of an open path optical fiber based sensor for Oxygen detection is shown in Figure 2. The apparatus used is described as four major sections, which are:

i. DH2000-BAL provided by Ocean Optics Inc. combine deuterium and halogen light source was used as the light source in this experiment. The combination of this two light source will provide continuous light in the wavelength of 190 nm until 2000 nm which will cover the whole UV region enabling investigation of the O_2 gas absorption located around 200 nm until 230 nm. For this reason, the deuterium source was chosen as the UV O_2 demonstration source.

ii. A stainless steel gas cell (750 mm long and 8 mm inner diameter) employed for the experiment was mounted with collimating lens at both ends will be used to measure the O_2 absorption line. This criterion was suitable for higher wavelength and temperature. However, for this experiment, it exhibited a high optical power loss and it is proposed to construct a similar gas cell with higher optical power transmission.

iii. Since the light source intensity is not linear, a charge coupled device (CCD) spectrometer which has better UV sensitivity is going to be used as UV detector. In this experiment, a miniature spectrometer, HR2000 from Ocean Optics is being used.

iv. The developed application by using SpectraSuite provide by Ocean Optics Inc. is being used as the software to calculate, analyze and obtain the absorption graph of oxygen gas.

IV. EXPERIMENTAL RESULTS

The experiment is carried out in a room where the surrounding temperature is approximately 27ºC. Before oxygen is measured, nitrogen gas is released into the gas cell to remove any available gases. The light source is switched on for 15 minutes to stabilize the intensity. Once oxygen gas is released into the test cell, the intensity reading is recorded using Spectrasuite software provided by Ocean Optics Inc. The integration time is set to 1 s. Absorption of the transmitted beam by oxygen gas is detected by the miniature spectrometer. These intensities values were plugged into the Beer-Lambert Law equation to obtain the absorption cross section. This absorption cross section acquisition method has been explained earlier in the previous report [26-27].

The result of the measured oxygen is shown in Figure 3. It shows an absorption cross-section spectra of 99.9% pure oxygen gas and its trendline using a spreadsheet. The trendline is set to a polynomial with a degree of two. Figure 3 also shows the theoretical absorption cross section for oxygen reported previously by many researchers [28-31]. It can be seen the shape of oxygen trendline has a similar shape to the theoretical data provided. The experimentally measured spectra have higher absorption values as compared to the theoretical lines. As explained earlier, this is common due to many reasons such as the type of light source used and different type of detector. It can also due to temperature difference which may result in different absorption values. It is also clearly seen in the graph that the measured line has much better resolution compared to the others. This oxygen detection setup is much better for future development of the oxygen sensor as the exact wavelength can be selected for the purpose of detection. This experimental setup has its own advantages and their working principle have been explained previously by Nurulain et al. [32].

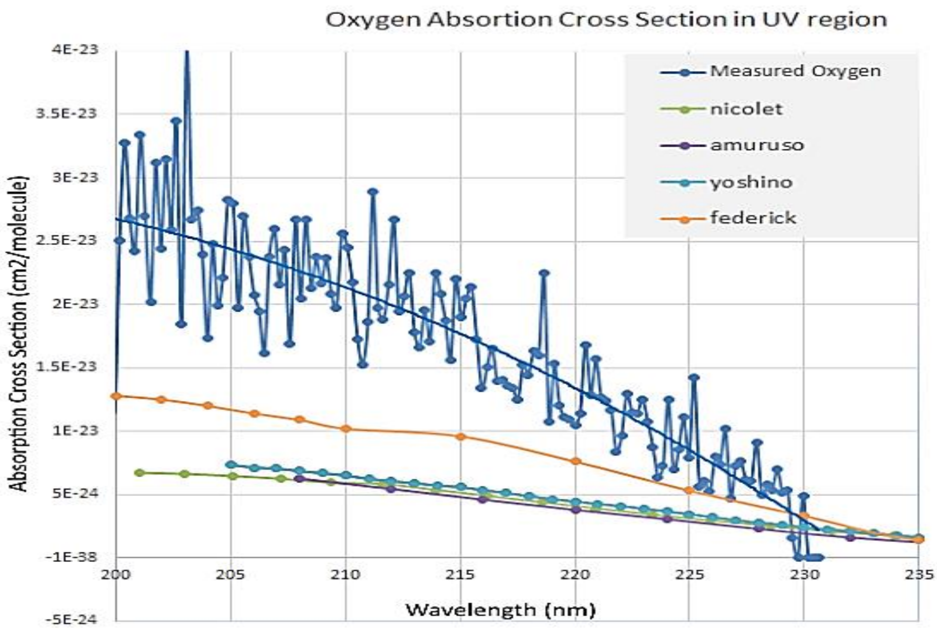

Figure 3: Oxygen absorption cross section spectrum between 200 nm and 230 nm.

Therefore, it is a clear that this setup has more advantage to measure oxygen absorption cross section within the wavelength region especially at a range of 200 nm – 230 nm. Hence the future developed sensor using this setup is expected to carry out the better measurement in term of accuracy and sensitivity. It is also expected to provide more advantages relative to the sensor with different absorption bands such as infrared.

V. CONCLUSION

This paper has reported that a potential development of a UV optical fibre based sensor for the detection of oxygen. The result has shown that the setup is able to detect oxygen at a range of 200 nm – 230 nm and the trendline for measured oxygen displayed has a similar shape with the spectrum from the MPI Mainsz database. This initial result is crucial in the development of the UV based oxygen optical fibre sensor in the future. Future work will focus on the cross sensitivity of other car exhaust gases such as carbon monoxide, sulfur dioxide, water vapour, etc.

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