

# Decomposition of Carbon Dioxide Gas Observation Using Optical Emission Spectroscopy Technique

Muhammad Daniel Faris Dzulkarnain<sup>1</sup>, Riyaz Ahmad Mohamed Ali<sup>1\*</sup>, Nur Aqilah Saidon<sup>1</sup>

<sup>1</sup> Faculty of Electrical and Electronic Engineering  
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

\*Corresponding Author: [riyaz@uthm.edu.my](mailto:riyaz@uthm.edu.my)  
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## Abstract

Carbon dioxide (CO<sub>2</sub>) is a key component for the main atmospheric and industrial processes but it may cause a harm to the environment seriously if released excessively to the air. Optical emission spectroscopy (OES) is a non-intrusive and widely used technique for analyzing plasma generated light to detect and identify gaseous species including CO<sub>2</sub>. This paper focuses on the observation and decomposition of gas CO<sub>2</sub> using OES aimed at isolating and interpreting the characteristics emission lines of CO<sub>2</sub> and its dissociation byproducts. In this study, we use RIE system as a main optical emission experiment for gas CO<sub>2</sub>. To find the reading intensity in plasma chamber of RIE system, we use 2 software tools which are *spectrasuite* as a main platform to find reading gas intensity and *originlab* as a plot graph for comparison different voltage and different working pressure. During the experiment, gas at different voltages such as 50 V, 100 V, 150 V, 200 V, 250 V, 300 V and 350 V and different working pressure such as 50 milliTorr, 100 milliTorr, 150 milliTorr and 200milliTorr, were being set. The findings from this study shows that at all working pressure and wavelength values, the input power is directly proportional to the produced gas intensity. Moreover, the use of OES combined with spectral decomposition proves to be an effective tool for the precise analysis of complex gas mixtures. This research lays the groundworks for future innovations in gas sensing technologies and emission control strategies involving CO<sub>2</sub>.

## 1. Introduction

Carbon dioxide or CO<sub>2</sub> is a gas that existed during the dinosaur era until present day. Two best friend gases which are gas carbon and gas oxygen not only maintain the ozone of our earth but they also contribute to the photosynthesis process for plants to keep growing taller. Gas carbon obtains through animal and plant decay while gas oxygen provides the safe gas for living things to smell the fresh air. Now in today era, the community does not care the effect of unbalance amount gas of CO<sub>2</sub> by establishing more factory that used so much resource that can create a black carbon gas which the origin is from the hydrocarbons such as oil or natural gas that factory used is incompletely combusted or thermally decomposed and forming elemental carbon particle.

The unbalance of CO<sub>2</sub> atoms can bring not only suffering to human beings but also to the environment and the animal too. The unbalance of CO<sub>2</sub> will create a greenhouse effect in which the black carbon gas cannot evaporate into space for a long time. The unbalance of CO<sub>2</sub> atoms can also make the layer of ozone become thinner which means it cannot provide a large portion of gas oxygen. When it does not provide a large portion of gas oxygen, the

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person will have difficulty breathing or even worse asthma. To keep gas CO<sub>2</sub> from becoming a disaster, the government and the community give shoulder to shoulder with each other to make earth become a better place. To maintain gas CO<sub>2</sub> is by reducing energy consumption in all vehicles to the renewable energy sources such as solar, wind, water and other than that. Not only it can maintain gas CO<sub>2</sub> purely but it also improves agricultural practices.

## 1.1 Problem Statement

There are 3 main problems to conduct experiments for gas CO<sub>2</sub> observation. First of the main problem is the unknown measurement deconvolution CO<sub>2</sub> wavelength. Wavelengths in gas compounds represent the measurement of how much "spread out" particles due to the thermal energy or inversely proportional particle momentum. This statement also can be strength up by related to the thermal de Broglie wavelength by it formula of  $\lambda = h / \sqrt{2\pi mkT}$  where h is Planck constant, m is the mass of the particle, k is Boltzmann constant and T is the absolute temperature [1]. Without a proper wavelength measurement, the experiment cannot be conducted properly and become error reading. While CO<sub>2</sub> is widely known for its greenhouse effect, the detailed analysis of its optical characteristics can be done through spectroscopic techniques such as optical emission spectroscopy remain limited. Several crucial gaps exist in the body of knowledge especially in the areas of wavelength decomposition, line emission and parameter analysis associated with CO<sub>2</sub> under plasma or high energy excitation conditions. These gaps limit the ability to accurately detect, quantify, and model CO<sub>2</sub> behavior in both environmental and industrial monitoring systems.

Second main problem to conduct the experiment is the unknown line emission of CO<sub>2</sub>. Line emission in gas compounds refers to the atom, element or molecule in an excited state returning to the lower energy [2]. Optical emission spectroscopy relies on heavenly identifying unique spectral lines corresponding to the electronic transitions of molecules or atoms. However, the line emission of CO<sub>2</sub> is not well documented in OES reference spectra due to the molecular complexity and the indirect nature of CO<sub>2</sub> electronic transitions. The lack of reference data makes it more difficult to differentiate CO<sub>2</sub> emission from other components in a plasma mixture. The lack of reference data also becomes an obstacle to the development of reliable CO<sub>2</sub> detections systems based on OES and reduces the accuracy of quantitative measurements.

The final main problem to conduct the experiment is the unknown parameter CO<sub>2</sub> deconvolution. General knowledge of parameters refers to the measurement factor or characteristic that defines the system or sets the condition for its behavior [3]. Parameter is very important to describe the state of gas and its behavior under certain conditions such as pressure, volume, temperature, and the number of moles especially when moving from ideal to the real gas behavior [3]. Spectral deconvolution also requires knowledge of several parameters such as full width at half maximum (FWHM), peak positions, intensity ratios, and instrumental broadening factors. Without standardized parameters or baseline values, the deconvolution process becomes arbitrary and unreliable, leading to inconsistencies in data interpretation and reproducibility. This problem will slow down the advancement of CO<sub>2</sub> monitoring applications especially in high precision environments such as combustion diagnostics, industrial plasma systems, and atmospheric sensing.

## 2. Definition of Plasma

Plasma is often referred to as the fourth state of matter, alongside solids, liquids, and gases. It is a high-energy state where atoms or molecules are ionized, meaning electrons are stripped away from their nucleus. This results in a mixture of free electrons and positively charged ions. The ionized state exhibits unique properties such as high electrical conductivity, responsiveness to magnetic and electric fields and collective behavior of particles. According to the US Department of Energy [4], plasma consists of free electrons and ions that are not bound together which allows it to conduct electricity and respond dynamically to electromagnetic fields. This behavior differentiates plasma from the other three states of matter such that free movement of charged particles does not occur.

### 2.1 Characteristic of Plasma

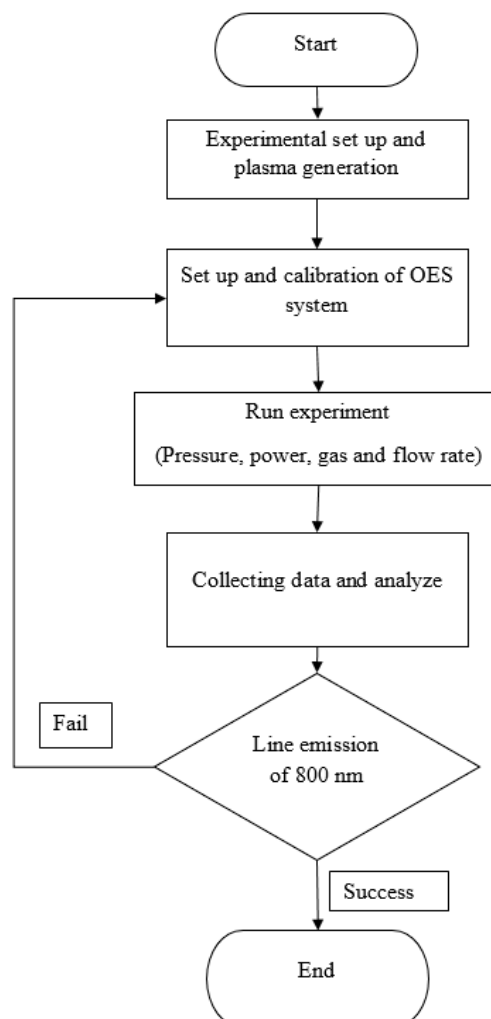
Characteristic plasma is it becomes electrical neutral and atoms move freely when there is a form of electric and magnetic field that cannot be seen in other forms of matter [5]. Not only does plasma move freely because of electric and magnetic, there are several characteristics that can be described to the plasma such as ionization, conductivity, magnetic response, and high energy. First of characteristic in plasma is that it has ionization.

Definition of ionization is a process of ions formed by gain or loss of an electron from an atom or molecule. This means in plasma; it has charge particles which are ions and electrons. Both ions and plasma must balance its quantity to avoid over reaction which can harm the surrounding people. Second of characteristic in plasma is conductivity. Definition of conductivity is a measurement ability to conduct electricity [6]. This means when the atom in a plasma state is moving freely, it will conduct an amount of electricity. Third of characteristic in plasma

is its magnetic response. Magnetic response meaning it is a fundamental concept in the field of magnetism that responds to a material to an applied magnetic field [7]. This means in a plasma state; atoms can be influenced by magnetic and electric fields which can phenomena such as aurora. Last of characteristic in plasma is it has high energy. Energy in chemistry is defined as the capacity to supply heat or do work [8-9]. The amount of energy can determine the amount to conduct electricity, kinetic and other than that. This means in a plasma state, the amount of movement of atoms can generate heat or electricity.

### 3. Flowchart of OES Technique

For initial OES setup, the experiment begins with the initiation phase, in which all necessary preparation and safety checks are performed as shown in Fig. 1. In the experimental setup and plasma generation part, once the system is ready the experimental setup can be used and running. This process includes arranging all components of the OES system such as plasma source, spectrometer, light collection system and detector. After the setup is complete, plasma can be generated using a suitable source such as inductively coupled plasma or glow discharge plasma. This step can create the medium of excitation which is very essential for the emission of light by the elements in the sample. For example, in the Wisconsin HTS Axisymmetric Mirror (WHAM) experiment, the integration of a portable diagnostic package facilitated comprehensive impurity line survey and plasma flow measurement through OES.



**Fig. 1** Flowchart of process optical emission spectroscopy (OES) technique

To ensure the accuracy and reliable measurement, the OES system must be calibrated first before proceeding with the experiment. This process is involved with adjusting the spectrometer and the detector to identify the measure characteristic spectral line of the elements under study. The calibration before doing any experiment is very crucial as it can minimize the errors and enhance the precision result of the experiment [10]. Proper

alignment and insulation between plasma stand and optical system are very important as it can prevent electrical flashovers and can ensure measurement accuracy.

With the OES system calibrated, the experiment can be conducted smoothly. During the experiment process, the key parameters such as pressure, power, type of gas, and flow rate gas must be adjusted first to optimize the plasma condition. These parameters can be a significant influence to the quality of the plasma and its intensity of the emitted spectral lines which mean this step is very critical to obtain meaningful data [11]. For example, in microcavity plasma arrays, precise control of parameters enabled near-complete oxygen dissociation as determined via helium state-enhanced actinometry.

Data from the experiment can be collected from the detector as the experiment progresses. The emitted light from plasma can record its result and its spectral lines can be analyzed to identify the element present and its concentrations. This step process involves both qualitative and quantitative analysis which means we can provide insights into the composition of the sample [12]. Calibration procedure is very important to ensuring the accuracy and reliability of OES measurements, the effective calibration methods include external standard calibration, internal standard calibration and standard addition method. There are different calibration methods. For example, external standard calibration can utilize known standards to establish a calibration curve. Internal standard calibration uses an incorporating an internal standard to account for matrix effects and instrumental variation [13]. Standard addition method uses adding known quantities of analyte to the sample to correct for matrix effects [14]. By using this method, we can minimize errors and enhance the precision of the experiment

Finally, in line emission a specific objective for the experiment is to evaluate the line emission at the desired wavelength such as 800 nm. If the emission line reaches its range, the experiment can be concluded that can fulfil the condition but if the emission line is not reached between the range, it must revisit back to the set up and calibration of the OES system for troubleshoot purposes and to improve the experiment condition.

#### 4. Results and Discussion

The RIE system is used as a main experiment to observe gas decomposition of CO<sub>2</sub> and as main optical emission, we can obtain reading results for intensity by observing different wavelengths, different working pressure and different power. The wavelengths that we observe for this experiment are 481.21 nm, 517.16 nm and 558.08 nm.

The power that is used during obtaining reading intensity are from 50 watt to 350 watt and the working pressure that is also used to obtain reading intensity are from 50 milliTorr to 200 milliTorr. The flow rate that was used during the experiment is 50 sccm which is value fixed for this experiment. Tables 1 to 3 are the recorded results through experiment gas CO<sub>2</sub> using the RIE system as main optical emission.

In addition, Figs. 2 to 4 show the variation of gas intensity produced for each condition setting. The result shows that the at all working pressure and wavelength values, the input power is directly proportional to the produced gas intensity.

**Table 1** Intensity of optical emission obtained at 50 sccm working pressure and wavelength of 481.21 nm

	50 milliTorr	100 milliTorr	150 milliTorr	200 milliTorr
50 Watt	1598	1638	1656	1762
100 Watt	2037	2181	2344	2488
150 Watt	2450	2578	2845	3193
200 Watt	2805	2970	3273	3795
250 Watt	3112	3279	3732	4290
300 Watt	3399	3644	4149	4811
350 Watt	3934	3941	4506	5195

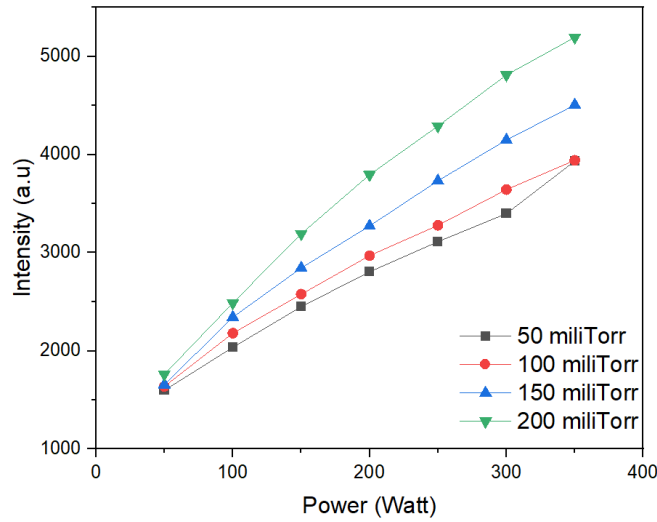


Fig. 2 Combination graph for power versus intensity for different pressure at wavelength of 481.21 nm

Table 2 Intensity of optical emission obtained at 50 sccm working pressure and wavelength of 517.16 nm

	50 milli Torr	100 milli Torr	150 milli Torr	200 milli Torr
50 watt	1573	1609	1604	1713
100 watt	2018	2186	2327	2558
150 watt	2497	2660	2932	3288
200 watt	2881	3061	3420	3982
250 watt	3175	3475	3886	4529
300 watt	3518	3847	4318	5067
350 watt	3789	4146	4743	5561

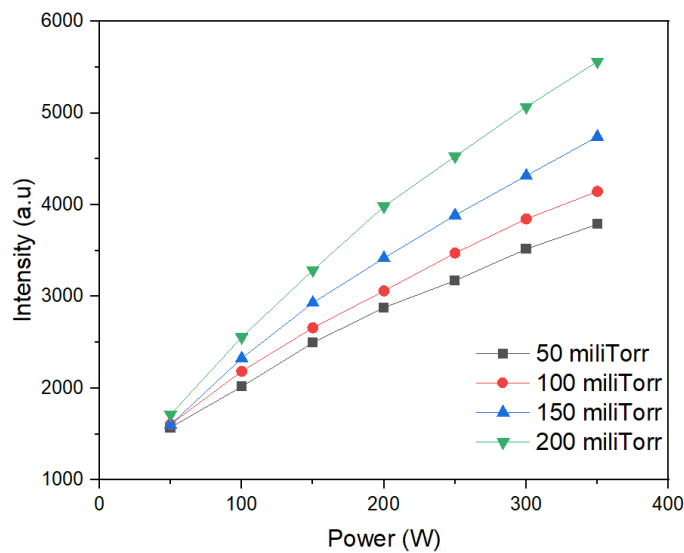
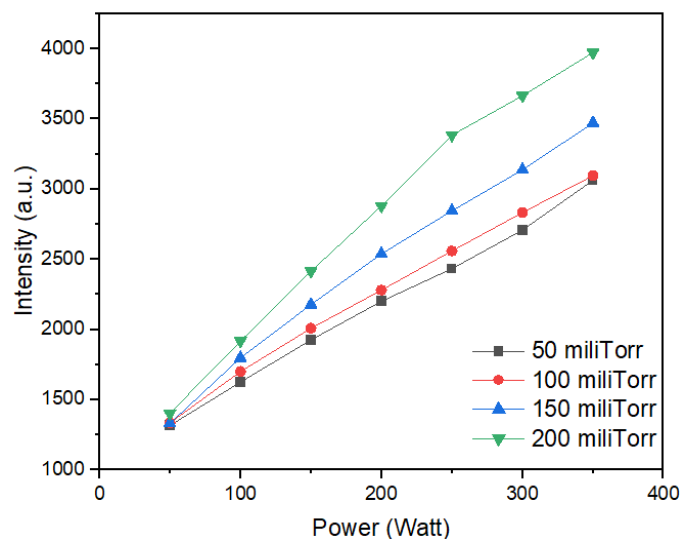


Fig. 3 Combination graph for power versus intensity for different pressure at wavelength of 517.16 nm

**Table 3** Intensity of optical emission obtained at 50 sccm working pressure and wavelength of 558.08 nm

	50 milliTorr	100 milliTorr	150 milliTorr	200 milliTorr
50 Watt	1315	1334	1330	1402
100 Watt	1624	1700	1797	1918
150 Watt	1925	2008	2177	2414
200 Watt	2200	2280	2539	2880
250 Watt	2433	2559	2845	3385
300 Watt	2708	2833	3137	3665
350 Watt	3063	3096	3471	3972

**Fig. 4** Combination graph for power versus intensity for different pressure at wavelength of 558.08 nm

## 5. Conclusion

Based on the result obtained from the experiment of gas observation CO<sub>2</sub>, we can conclude that there is a direct relationship between RF power, plasma intensity and working pressure within the RIE system. As the power applied increases, the intensity of plasma emission also will increase which indicates it has stronger excitation and ionization of gas molecules. The rise in intensity also allows the system to operate more effectively at higher working pressures. Besides that, the higher working pressure contribution can contribute to enhancing particle collisions which result in the production of more emitted light within the plasma chamber. Overall, optimizing the RF power not only improves emission intensity but also facilitates stable plasma generation at elevated pressures which can lead to more efficient gas excitation and light emission during decomposition gas CO<sub>2</sub> analysis.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception, design, data analysis and manuscript preparation:** Muhammad Daniel Faris Dzulkarnain; **manuscript verification:** Riyaz Ahmad Mohamed Ali. All authors reviewed the results and approved the final version of the manuscript.

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