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Detecting Photoacoustic Signals of Sulfur Hexafluoride at Varying Microphone Positions

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Abstract

Photoacoustic spectroscopy was used to test the photoacoustic properties of sulfur hexafluoride, an optically thick and potent greenhouse gas. While exploring the photoacoustic effect of sulfur hexafluoride, the effects of the position of the microphone within a gas cell were determined. Using a 35 cm gas cell, microphones were positioned at 17.5 cm, the middle of the gas cell, 12.5 cm, 7.5 cm, and 2.5 cm from the window of the cell. From the photoacoustic signal produced for each resonance frequency at each microphone position, the effects of acoustic pressure produced at each position on the signal recorded were observed. This is the first study done by experimentation with the photoacoustic effect to show that standing waves have different amplitudes at different microphone positions.

1. Introduction

In 1880, Alexander Graham Bell discovered the phenomenon that was the photoacoustic effect [1]. Through experimentations with his photophone, Bell's discoveries determined that measureable acoustic waves could be detected when modulated optical radiation was directed towards a gaseous, liquid, or solid material [2]. The light directed onto an object results in thermal excitation of the object, thus resulting in thermal expansion. However, since the light is modulated, excitation as well as de-excitation takes place causing expansion and contraction of the molecules making up the material. The periodic expansion and contraction of the material's

molecules result in the production of detectable and measurable acoustic waves [3].

Due to the acoustic waves produced by the photoacoustic effect, pressure builds up within a gas cell. At resonance frequencies, the acoustic pressure created forms areas of maximum amplitudes within the cell. A microphone positioned within the cell is capable of detecting the audible pressure fluctuations, and an oscilloscope is used to convert the detected signals into a visible waveform for recording [4]. A diagram displaying the pressure amplitudes within the gas cell at different resonance frequencies can be seen in **Figure 1** [5]. The signal amplitude, displayed by the oscilloscope, is capable of reflecting the amplitude of acoustic pressure at that particular location and resonance [6]. Through the placement of microphones at varying positions across a gas cell, the photoacoustic signal generated can be detected and compared to the pressure fluctuations and their amplitudes at these varying positions as represented by **Figure 1**. Sulfur hexafluoride (SF_6) is a man-made gas used in electrical transmission equipment, semiconductor manufacturing, and has become the most commonly used insulating gas in electrical systems. Due to the increased production of SF_6 and its prolonged lifetime within the atmosphere, detection of its leaks has become a growing concern. Since SF_6 is a strongly absorbing gas, with a large optical absorption coefficient at a wavelength of 10.6 μm, it is the ideal gas for detection using photoacoustic spectroscopy. The large absorbance peak at 10.6 μm is the reason for using a CO_2 laser here [7]. In this research, the effects of the position of the microphone within a gas cell containing SF_6 were determined.

2. Methods/Procedures

A 35 cm gas cell was constructed using three 10 cm gas cells and one 5 cm gas cell (RJ Spectroscopy Company). Four electret microphone elements (RadioShack, 270-092) were fixed to the top of four inlet/outlet ports using short segments of rubber tubing and Parafilm laboratory film. The microphones were placed so that one microphone was positioned in the middle of the gas cell, 17.5 cm, and the other microphones were positioned at 12.5, 7.5, and 2.5 cm from one of the gas cell's germanium windows (Thorlabs, Inc.). The germanium windows were used due to their low absorption at the wavelength of the laser used and to minimize the effects of moisture on the experiment. The microphones were connected to a voltage amplifier (Femto, Model HVA-10M-60-B) and a digital oscilloscope (Tektronix, TBS 1202B). A diagram of the gas cell and the placement of the microphones can be found in **Figure 2**.

The microphone positioned at 17.5 cm was connected to a power source and the oscilloscope. After filling the gas cell with SF_6, a CO_2 laser (Access Laser Company, L3) was used to excite the gas molecules. Since the laser used is a continuous laser, an optical chopper (Thorlabs, Inc.) was placed in the middle of the alignment of the CO_2 laser and the gas cell in order to modulate the light. Also, a 600 - 700 nm laser (Thorlabs, Inc., CPS182) was used as a reference laser and detected by a Si photo detector (Thorlabs, Inc., DET36A). The Si detector was also connected to the oscilloscope. A diagram of the experimental setup used can be seen in **Figure 3**. The
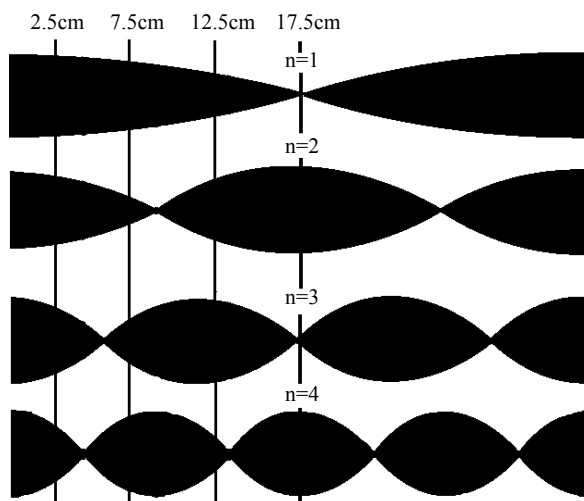

Figure 1. Diagram of pressure waves formed at the first four resonance frequencies with microphone placement [5].
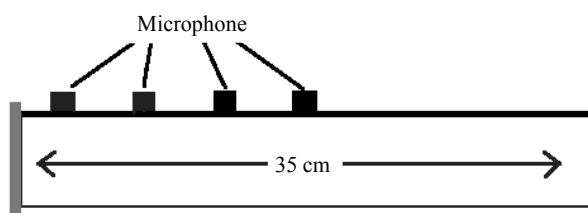
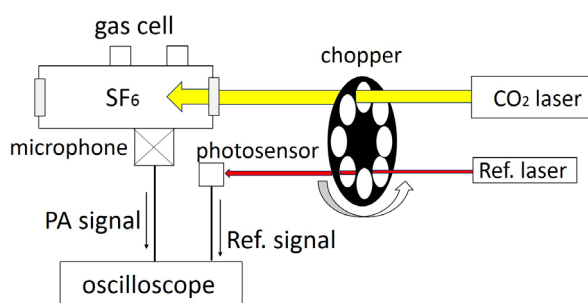**Figure 2.** Diagram of gas cell setup with microphones.

Figure 3. Diagram of experimental setup.

amplitude of the sound waves produced was measured by the oscilloscope and recorded for each frequency increment using 10 Hz increments from 100 Hz to 1000 Hz. When a resonance frequency was found, 1 Hz increments, the lowest possible increment for the chopper used, were used to determine the exact frequency. Each resonance frequency was measured to its precise frequency and recorded. This process was also completed for the microphones positioned at 12.5, 7.5, and 2.5 cm.

In order to show reproducibility, the procedure and process previously mentioned was completed for a total of three times over a period of two weeks. Similar experimental conditions were provided for each trial: room temperature, one-third power setting for CO_2 laser, and a 35 cm gas cell containing 100% SF_6. Data in **Figures 4-7** represent the average of 64 replicates.

3. Results and Discussion

Within the gas cell, nodes are formed at each resonance frequency due to the amplitude of pressure caused by the acoustic waves [5]. As previously mentioned, a representation of the pressure waves produced due to the photoacoustic effect can be found in **Figure 1**. Resonance frequencies were determined for each microphone position. The recorded measurement of the photoacoustic signal determined at each of these resonance frequencies can be found in **Table 1**. The signal versus frequency plot for positions 2.5, 7.5, 12.5, 17.5 cm can be found as **Figures 4-7**, respectively.

Since a 35 cm gas cell was used, the microphone positioned at 17.5 cm is in the middle of the cell, and the microphone positioned at 2.5 cm is most towards the outer edge of the diagram found in **Figure 1**. The amplitude of the pressure wave at the position of the microphone at each resonance should correspond to the signal detected by the microphone at that resonance. The results obtained from **Figures 4-7** confirm the previous assumption. At low-pressure wave amplitudes the signal is lower in strength than at high-pressure wave amplitudes. The results obtained were consistent for all four of the positions.

Due to the optical thickness and high absorption coefficient of SF_6 at a wavelength of 10.6 μm most of the light from the CO_2 laser is absorbed at the incident point at which the light comes into contact with the gas [8]. Because of the high absorbance of light at this part of the gas cell, the corresponding photoacoustic signal produced should be the maximum signal recorded at the first resonance frequency. From the data collected in **Table 1**, the previous statement stands true.

4. Conclusion

The effects of the position of a microphone within a gas cell containing SF_6, an optically thick, greenhouse gas,
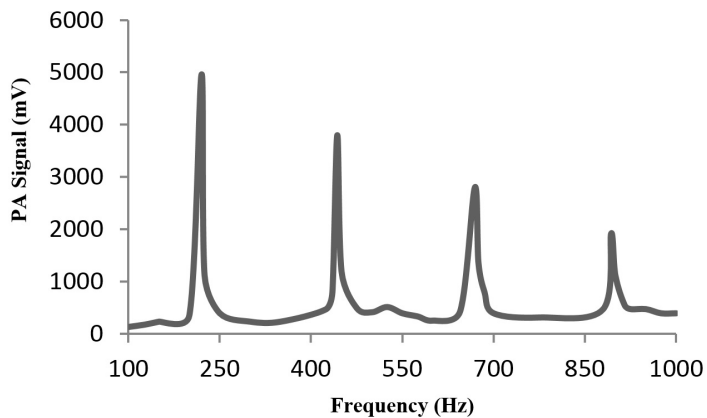
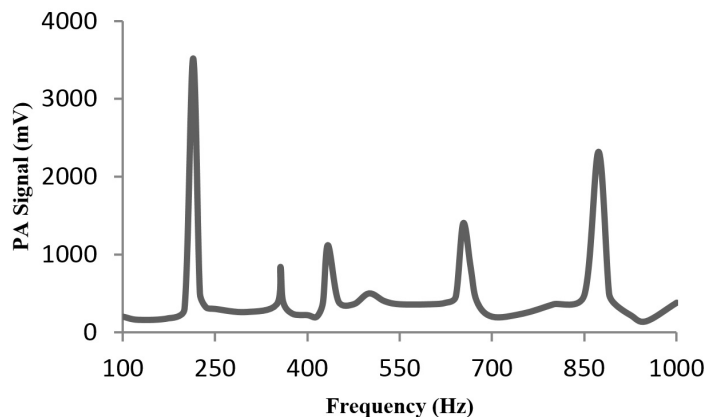**Figure 4.** Photoacoustic signal vs. frequency for microphone positioned at 2.5 cm.

Figure 5. Photoacoustic signal vs. frequency for microphone positioned at 7.5 cm.
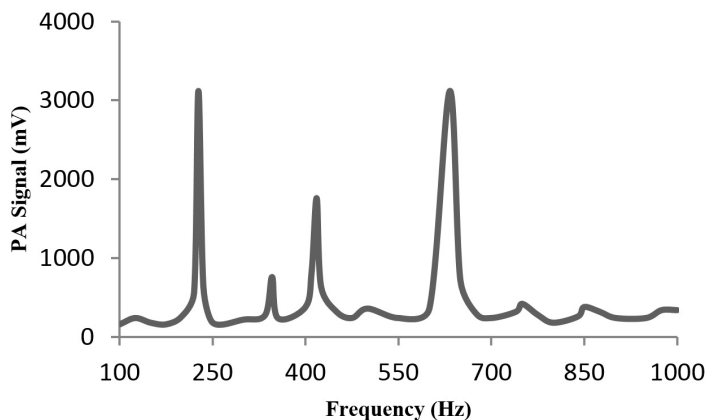

Figure 6. Photoacoustic signal vs. frequency for microphone positioned at 12.5 cm.

have been determined. Through the use of a photoacoustic spectroscopy technique and detection of pressure amplitudes within the gas cell, it was determined that the signals detected from the microphones corresponded to the amplitude of pressure waves at particular resonance frequencies within particular areas of the gas cell. The position of a microphone within a gas cell is an experimental condition that has yet to be tested to determine its
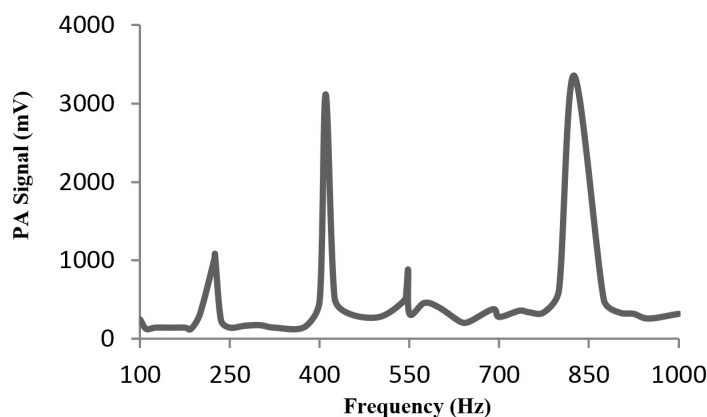
Figure 7. Photoacoustic signal vs. frequency for microphone positioned at 17.5 cm.

Table 1. PA signal detected at each resonance frequency for varying microphone positions.

Position of Microphone (cm)	Signal at 1st Resonance (mV)	Signal at 2nd Resonance (mV)	Signal at 3rd Resonance (mV)	Signal at 4th Resonance (mV)
2.5	4960	3800	2800	1920
7.5	3520	1120	1400	2320
12.5	3120	1760	3120	380
17.5	1080	3120	380	3360

effect on detecting photoacoustic pressure signals. The data collected can be beneficial in the positioning of microphones for detecting trace amounts of gas if the "n" value of the resonance frequency is known. The results of this experimentation display how resonance frequency, peak amplitude useful in trace amount detection, is related to the proper position of the microphone, a technique that can be advantageous in conventional photoacoustic experiments. This experiment is also the first study to use the photoacoustic effect to show that standing waves have different amplitudes at different positions.

Acknowledgements

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