Study on Separation Procedure of Predominantly Overlapped Two Absorption Signals for Concentration Measurement in TDLAS Method

Miyeon Yoo[1], Saerom Maeng[1,2], Sunghyun So[1,2], and Changyeop Lee[1]
[1]Korea Institute of Industrial Technology, Cheonan, Republic of Korea
[2]Yonsei University, Seoul, Republic of Korea
Email: {myyoo, saerom, shso, cylee}@kitech.re.kr

***Abstract*—Tunable Diode Laser Absorption Spectroscopy (TDLAS) is becoming more important method to measure the physical properties in real time such as temperature, gas concentration, velocity and pressure. It is more useful in huge combustion systems because of their harsh environment conditions. And a combustion gas concentration like CO and CO_2 can be a factor to indicate the energy efficiency of a combustion system. In this study, a research was carried out to calculate the respective gas concentrations of two species mixture using TDLAS method. Experiments were performed to calculate the respective gas concentrations of a mixed gas by analyzing two types of wavelength absorption signals, one gas affected absorption signal and combined absorption signal. And its results were compared with actual concentration values of the mixture. As a result, each gas concentration can be well-calculated by proposed method in this article, even if there is no independent absorption signal of a measurement target gas of the mixture.**

***Index Terms*—concentration, carbon dioxide, carbon monoxide, tunable diode laser absorption spectroscopy**

I. Introduction

Carbon dioxide (CO_2) is a representative object gas for exhaust gas monitoring in hydrocarbon fueled energy systems. And Carbon monoxide (CO) is a particularly important gas for hydrocarbon fueled combustion systems, since it is a toxic pollutant as a primary product by incomplete combustion and its concentration can be a reference to indicate the combustion efficiency [1], [2]. Then, real time measurement is strongly recommended because CO and CO_2 gas concentration is directly affected by combustion efficiency.

Most of typical gas concentration measurement equipments have several disadvantages. First of all, they need enough measurement time because it takes several seconds to collect the measurement target gas samples. And maintenance and calibration of sensor part and collecting part are needed frequently, otherwise, reliability of the measurement equipment becomes lower due to the contaminations of gas samples. Moreover, it is difficult to know the distribution of a gas of inner system as point measurement methods.

Tunable Diode Laser Absorption Spectroscopy is becoming more important method to measure the physical properties in real time such as temperature, gas concentration, velocity, flowrate and pressure. It is a measurement method that can overcome the problems presented in former paragraph, because it is a noncontact, real time, in situ measuring method. It has semi-permanent life, fast responsibility and high reliability, so several studies has been conducted to apply it in combustion area [3], [4].

However, at least one or more independent absorption signals regarding other gases are needed for one gas concentration calculation. Due to a considerable absorption signals affected by two or more gases, it can be favorable economically and technically if a calculation method uses combined absorption signal.

In this study, a novel measurement method was suggested to extend bound of TDLAS application. To obtain the concentration of CO in condition without only CO gas affected absorption signal, CO_2 absorption signal was used.

II. Fundamental Theory

The basic principle of TDLAS is based on the Beer-Lambert Law.

On the basis of Beer-Lambert Law, the integrated absorption is proportional to the partial pressure. Therefore, the concentration(X) of a gas species can be obtained simply as equation (1). [6], [7]

$$X = \frac{A}{P \cdot L \cdot S(T)} \tag{1}$$

where P[atm] is the pressure, L[cm] is the path length, $S(T)$[cm^{-2}/atm] is the linestrength of a particular wavelength and temperature and A is the integrated the area, respectively.

A gas concentration when two gas species(i, j) have a uniform mixture can be calculated using two absorption wavelength signal, one gas affected absorption signal and combined absorption signal. One gas affected absorption signal means the absorption signal in a wavelength region (region 1) where the light is absorbed by the gas species i

Manuscript received July 1, 2016; revised October 30, 2016.

doi: 10.18178/ijmerr.5.4.264-267

only, while the gas species j is transparent. Combined absorption signal means the absorption signal in a wavelength region (region 2) where the light is absorbed by two gas species at the same time although the absorptivity is different.

First, the gas concentration of i is calculated by one gas affected absorption signal in a wavelength region 1 using equation (1). The A_{i_2} that is the absorption area by gas species i in wavelength region 2 is calculated using the obtained gas concentration(X_{i_1}).

$$A_{i\_2} = X_{i\_1} \cdot P \cdot L \cdot S_{i_2}(T) \tag{2}$$

Then gas concentration of j can be calculated as equation (3) although there is no independent absorption signal only for j species.

$$X_{j\_2} = \frac{A_{total(i+j)} - A_{i\_2}}{P \cdot L \cdot S_{j\_2}(T)} \tag{3}$$

III. Experiment Setup and Condition

An experiment was conducted using a gas mixture of CO_2/CO. The measurement was performed 6373~6377 cm^{-1} wavelength range. There is no only CO-affected absorption signal in this wavelength region but other types of absorption signals, only CO_2-affected absorption signal(V_1) and CO&CO_2-affected absorption signal(V_2), were observed.

Fig. 1 is the schematic diagram of total experiment setup for gas concentration measurement. There is a gas cell and its path length is 409 cm. Component controlled CO and CO_2 mixture gas was filled in the gas cell. And a DFB type diode laser was used and its wavelength and intensity were controlled by laser controller. The DFB Laser wavelength can be tuned over the entire experimental region. A function generator was used to make a ramp featured optical signal.

The DFB laser was split into two beams by 1x2 optical coupler as shown in Fig. 1. One laser beam was launched and transmitted through the target gas cell and CO_2 and CO absorption signal was detected by an InGaAs photo diode detector. Another laser beam is propagated through a solid etalon to provide a calibration reference value of the wavelength.

A Data acquisition system and a computer was connected to the detector for data collection, analysis and calculation. Optical and electrial noises were removed by various hardware and software manners such as wedged lens and bandpass filter.

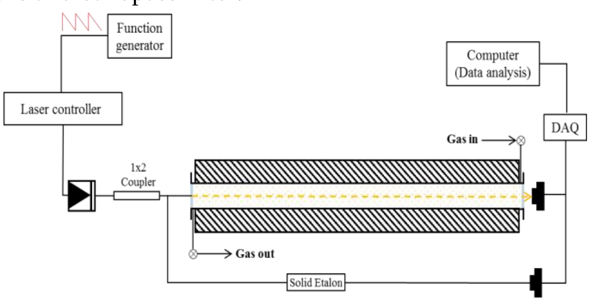

Figure 1. Experimental setup for concentration measurement

IV. Result

Fig. 2 is a simulation result by HITRAN database at room temperature (296K). As a simulation result, it was expected that absorption signal of CO(V_1) becomes strong signal but CO_2 absorption signal is also located at same wavelength. However, in case of CO_2, absorption signal (V_2) is weak but it is possible to secure independent signal from CO absorption, then it can be used to calculate exact CO_2 gas concentration.

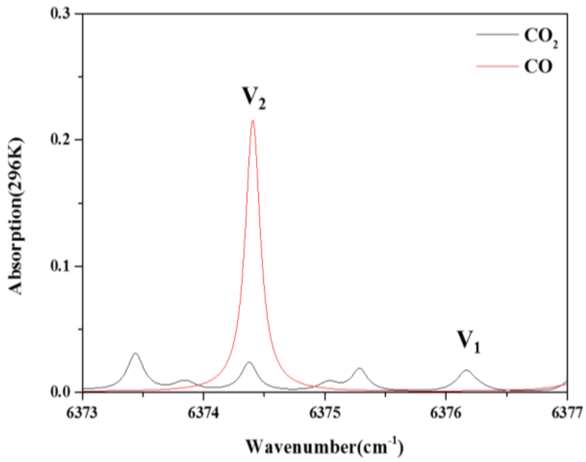

Figure 2. Simulation by HITRAN database (296K)

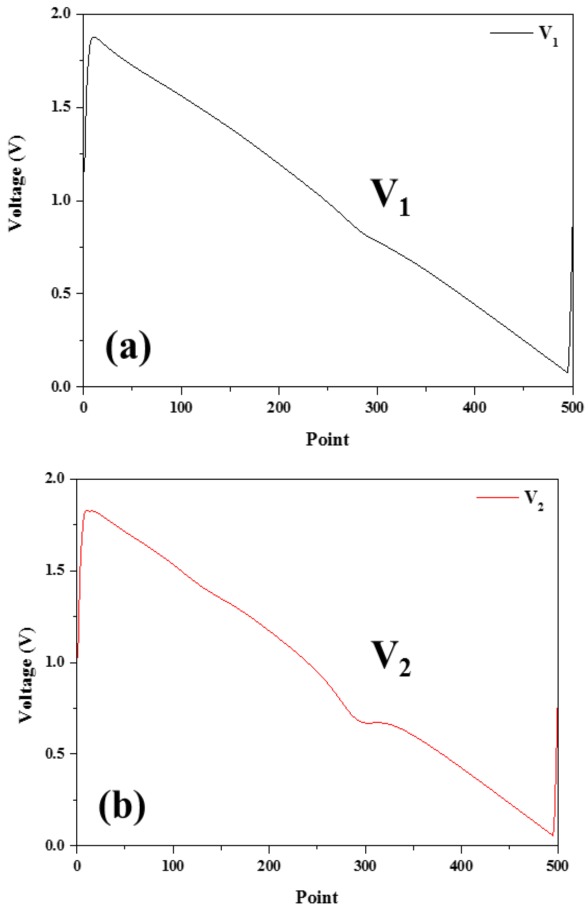

Figure 3. Original Absorption signals ((a)V_1_CO_2, (b)V_2_CO_2+CO)

Table I shows linestrength of CO and CO_2 at selected wavelength region. Linestrength of CO is big as almost 10 times of CO_2 linestength. And exact absorption wavenumbers of CO and CO_2 in V_2 region are different but very close location, so these two absorption signals were expected to show one absorption signal in real test environment because of line broadening effect. And line broadening effect becomes bigger at high temperature condition.

Fig. 3 shows original absorption signals obtained by a DFB laser control. Fig. 3(a) graph is the CO_2 absorption signal (V_1) and Fig. 3(b) graph is the CO&CO_2 combined absorption signal (V_2). Those are original graph with tuning a laser by ramp wave. And respective calibrated absorption signals according to the wavenumber are showed in Fig. 4.

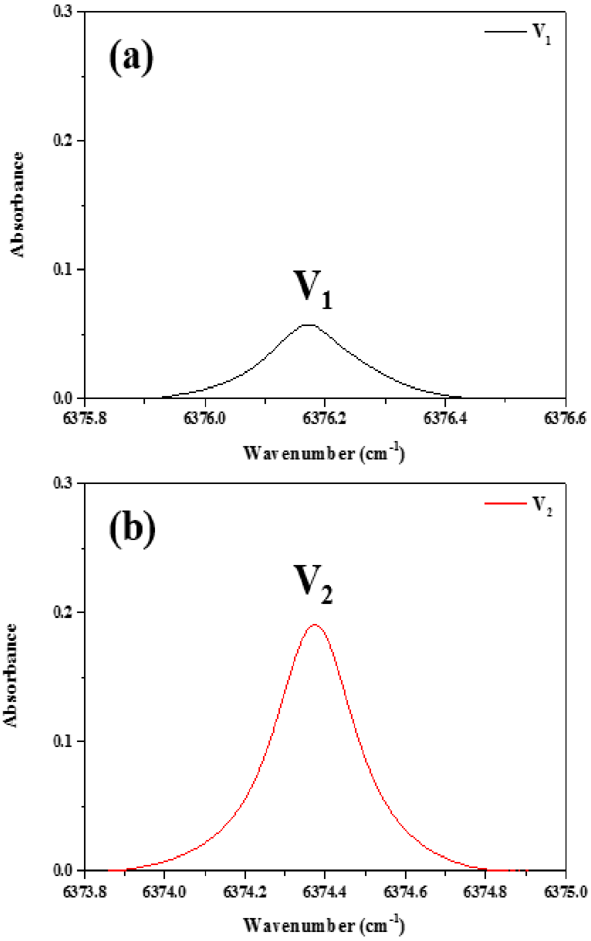

Figure 4. Calibrated absorption signals ((a)V_1_CO_2, (b)V_2_CO_2+CO)

TABLE I. LINESTRENGTH VALUES OF CO_2 AND CO

	Wavenumber, cm^{-1}	Linestrength, S(T)
V_1_CO_2	6376.1	1.29E-24
V_2_CO_2	6374.3	2.33E-24
V_2_CO	6374.4	2.15E-23

The concentration of CO_2 was calculated using one absorption wavelength (V_1). And acquired CO_2 concentration value was used to predict the portion CO_2 absorption area at V_2 absorption signal. Then only CO affected absorption area and CO concentration can be calculated as per Equation (3) discussed at theory paragraph. Absorption area values of each gases are showed in Fig. 5.

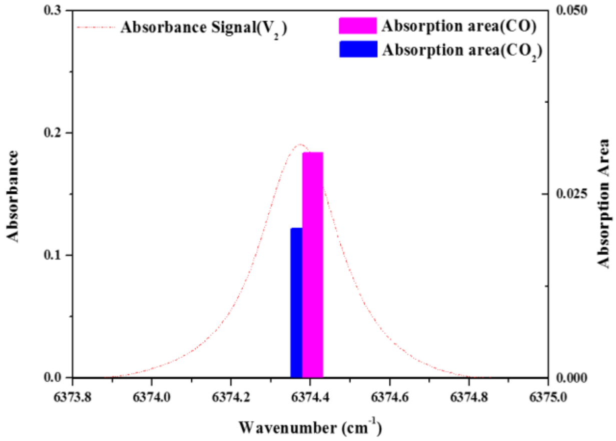

Figure 5. Combined absorption signal and absorption area values

Table II shows the calculated gas concentration result compared with real value.

TABLE II. RESULT OF CO_2 AND CO CONCENTRATION ANALYSIS

	Real gas Concentration (%)	Calculated gas Concentration (%)	Error Rate (%)
CO_2	85	86.02	1.2
CO	15	15.42	2.8

The CO_2 concentration in the mixture was calculated as 86.02%. The real value was 85%, then the error rate was found as 1.2%. And CO concentration in the mixture was calculated as 15.42%, while the real value was 15%. The error rate was 2.8%.

Accuracy of CO measurement was relatively low, but gas concentration was successfully obtained using equation 3 notwithstanding there is no CO only absorption signal.

V. SUMMARY

In this study, a TDLAS-based gas concentration measurement method was suggested in condition with two gas species are mixed. And it was focused on the gas concentration calculation of non-independent absorption signal condition.

A combined absorption signal that generally wasn't applied for concentration measurement was used and obtained the quite good result. Through the experiment, the possibility to measuring the respective gas concentration at actual environment condtion was confirmed, if there is no independent absorption signal of a target gas.

This result can be applied to the combustion system that various gases are mixed, and it provide a novel way to measure the gases which quantitative analysis are difficult.

ACKNOWLEDGMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20131020102330).

REFERENCES

[1] A. Farooq, J. B. Jeffries, and R. K. Hanson, “High-pressure measurements of CO_2 absorption near 2.7 ㎛: Line mixing and finite duration collision effects,” *Journal of Quantitative Spectroscopy & Radiative Transfer*, p. 949, 2010.

[2] K. Wu, F. Li, X. Cheng, Y. Yang, X. Lin, and Y. Xia, “Sensitive detection of CO_2 concentration and temperature for hot gases using quantum-cascade laser absorption spectroscopy near 4.2 ㎛,” *Appl. Phys, B*, 2014.

[3] H. Li, G. B. Rieker, X. Liu, J. B. Jeffries, and R. K. Hanson, “Extension of wavelength-modulation spectroscopy to large modulation depth for diode laser absorption measurements in high-pressure gases,” *Optical Society of America*, vol. 45, no. 5, 2006.

[4] M. G. Allen, “Diode laser absorption sensors for gas-dynamic and combustion flows,” *Measurement Science and Technology*, vol. 9, no. 4, p. 545, 1998.

[5] R. M. Mihalcea, D. S. Baer, and R. K. Hanson, “Advanced diode laser absorption sensor for in-situ combustion measurements of CO_2, H_2O, and gas temperature,” *Proceedings of the Combustion Institute*, vol. 27, p. 95, 1998.

[6] H. Xia, Z. Xu, R. Kan, Y. He, J. Liu, and G. Zhang, “Numerical study of two-dimensional water vapor concentration and temperature distribution of combustion zones using tunable diode laser absorption tomography,” *Infrared Physucs & Technology*, p. 170, 2015.

[7] A. Farooq, J. B. Jeffries, and R. K. Hanson, “In situ combustion measurements of H2O and temperature near 2.5 ㎛ using tunable diode laser absorption,” *Measurement Science and Technology*, p. 11, 2008.

Miyeon Yoo was born in Seoul, Korea. She was granted a physics master degree in Chungbuk National University in 2013. Her major is optics. She is working as a researcher in KITECH (Korea Institute of Industrial Technology) and studying on the laser spectroscopy.

Saerom Maeng was born in Seoul, Korea. She was granted a nano-science degree in Chungju university in 2009. She is studying as a mechanical Yonsei university and master course.

Sunghyun So was born in Changwon, Korea. He was granted a master degree in GNU(Gyungsang national university) in 2016. He is working as a researcher in KITECH (Korea Institute of Industrial Technology).

Changyeop Lee was born in Jeonju, Korea. He was granted a Ph.D degree in KAIST (Korea Advanced Institute of Science and Technology) in 2008. His major is precise measurement in harsh environments. He is working as a principal researcher in KITECH (Korea Institute of Industrial Technology) and devepling technologies on optical measurements. Dr. Lee is working in various mechanical academic society such as OSK (Optical Society of Korea) and KSME (Korea Society of Mechanical Engineering).