Advanced Science and Technology Letters
Vol.120 (GST 2015), pp.20-26
http://dx.doi.org/10.14257/astl.2015.120.04

Design of a high accuracy non-dispersive Infrared gas sensor for continuous emission monitoring of carbon monoxide emitted from an industrial stack

Trieu-Vuong Dinh[1], In- Young Choi[1], Bo Gao[1], Yong-Hwan Oh[1], Ji-Won Ahn[2], Jo-Chun Kim[1,2,*]

[1] Dept. of Environmental Engineering, Konkuk Univ., Seoul, Republic of Korea
[2] R&D Center for Green Patrol Technologies, Konkuk Univ., Seoul, Republic of Korea
* Contact: jckim@konkuk.ac.kr

Abstract. A continuous emission monitoring device based on non-dispersive Infrared (NDIR) for carbon monoxide emitted from an industrial stack was designed. A comparison on optical White cell and Herriot cell were conducted to select an optimal waveguide for the gas cell. Gas flow rate, infrared (IR) source, chopper frequency, gas cell temperature and detector types were also investigated to choose an optimal operating condition. It was found that the reflective capacity of Herriot cell was higher than that of White cell. However, it was difficult to arrange the locations of IR source and the detector in case of Herriott cell. It was observed that the gas cell temperature did not affect the detectivity of the NDIR sensor. On the other hand, gas flow rate, chopper frequency, IR source capacity and detector type significantly affected the performance of the sensor.

Keywords: Infrared, NDIR, industrial stack, CEMS, carbon monoxide.

1 Introduction

As an application of infrared spectroscopy, non-dispersive infrared (NDIR) gas measurement started in the late 1930's in the United States. The NDIR technique of gas measurement is based on the wavelength absorption in the infrared spectrum as a way to identify particular gases. NDIR technologies are amenable to the detection of air pollutants emitted from emission sources such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NOx), nitrous oxide (N_2O), ammonia (NH_3), hydrogen chloride (HCl) and methane (CH_4). A typical NDIR is shown in Fig. 1 [1-5].

An advantage of NDIR compared with other spectroscopy techniques is its low energy consumption. However, there are two major drawbacks of an NDIR sensor: interference and sensitivity. The sensitivity of NDIR is influenced by the intensity of the IR source, the optical waveguide, and the detector [6].

ISSN: 2287-1233 ASTL

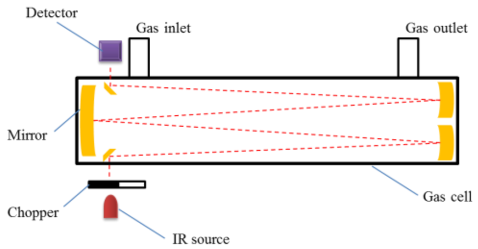

Fig. 1. A structure of an NDIR.

Therefore, the development of NDIR gas sensors has been continued. The objective of this present study is to design a high accuracy NDIR sensor for continuous emission monitoring of CO emitted from an industrial stack.

2 Experimental methods

2.1 Comparison of optical White and Herriot cells

Two concave mirrors coated with gold were used for Herriott cell [8]. Their focal length was 200 mm and their diameter was 50 mm. The center hole diameter of the mirror was 3 mm. White cell [7] was made using three concave mirrors coated with gold. Their focal length was 200 mm and their diameter was 75 mm. A pyro-electric detector with carbon monoxide band pass filter (4.6µm) was used to detect IR intensity for the NDIR sensor.

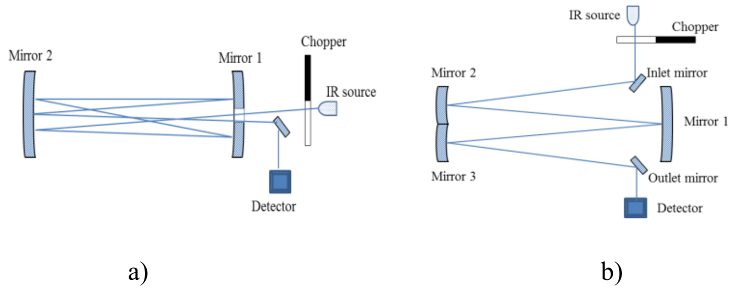

Fig. 2. Experimental set-up of Herriott cell (a) and White cell (b).

2.2 Selecting detector

The characteristics of available IR detector are shown in Table 1. The pyroelectric detector was selected due to the wide range of IR wavelength as well as the high detectivity and the independent ambient temperature.

Table 1. Classification of IR detector

Detector type	Spectral response (μm)	Temperature (K)	Detectivity (cm.Hz$^{1/2}$/W)
Pyro electric	Depends on window material	300	$2x10^8$
Thermopile			$6x10^8$
Bolometer			$1x10^8$
Pneumatice cell			$1x10^9$
Photoconductive (PbSe)	1.5 – 5.8	300	$1x10^9$
Photoconductive (HgCdTe)	2 – 16	77	$1x10^{10}$

2.3 Investigating optimal gas cell temperature

A gas chamber based on White cell with 5 m of waveguide length was used to investigate the effect of temperature on the NDIR sensor (Fig. 3). The temperature was varied as 30, 40, 50, 60 °C. The chopper frequency was set up at 30 Hz. The 20 W of IR source (Hawkeyetechnologies Inc., USA) was used to project IR beam. The IR detector used was pyro-electric type (LTG2M, Scitech instrument Ltd., UK). High purity nitrogen (Rigas Co., Ltd., Korea) and carbon monoxide (1%, Rigas Co., Ltd., Korea) were used in this work.

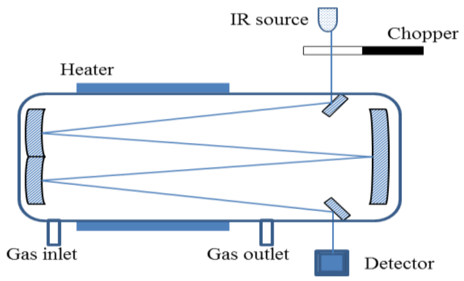

Fig. 3. Experimental set-up for gas cell temperature and optimal operation**.**

2.4 Investigating optimal chopper frequency, gas flow rate, and IR source power

The experimental set-up for optimal operation is shown in Fig. 3 without the heater. The chopper frequency was varied from 10 to 350 Hz. The gas flow rate was changed as 100, 500, 1000, 2000, 3000, 5000, 10000 mL/min. The IR source power was varied as 4, 11, 20, 30, 40 Watt.

3 Experimental results

3.1 Comparison on optical White and Herriot cells

The detector signal for White and Herriot cells is depicted in Fig. 4. It was observed that the detector signal for Herriot cell was higher than that of White cell. It indicated that the reflective efficiency of Herriot cell was better than that of White cell because the number of mirrors in Herriot cell was less than that in White one.

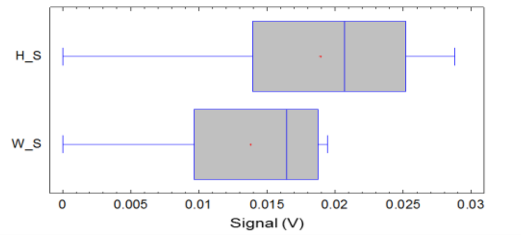

Fig. 4. Box and Whisker plot of detector signal for White cell (W_S) and Herriot cell (H_S).

3.2 Investigating optimal gas cell temperature

The experimental results are presented in Fig. 5. It was observed that the detectivity of the NDIR sensor was not affected by gas cell temperatures.

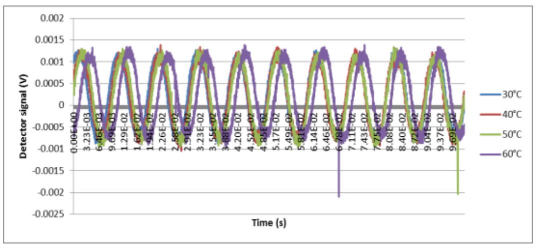

Fig. 5. Patterns of detector signal at different temperatures while introducing CO.

3.3 Investigating optimal chopper frequency, gas flow rate, and IR source power

The experimental results of chopper frequency, gas flow rate, and IR source power are presented in Fig. 6, Fig. 7, and Fig. 8, respectively. As shown in Fig.6, the optimal frequency of the chopper was approximately 100 Hz. The optimal frequency depended on the detector. This result was similar pattern to that of other research [9].

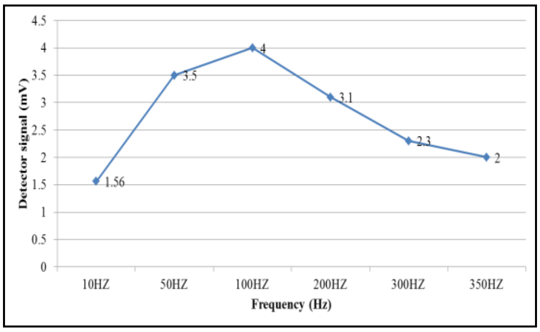

Fig. 6. Variations of detector signals with chopper frequencies.

The Fig. 8 indicated that when the gas flow rate was higher than 1000 mL/min, the absorptive capacity of target gas in the gas cell was the highest. Moreover, the increase of gas flow rate starting from 2000 mL/min did not change the absorptive capacity. In terms of IR source power, it was found that the higher IR power was, the higher sensor's detectivity was. However, using high power of IR would lead to high operation cost. Therefore, 20 W of IR source was selected as a reasonable one.

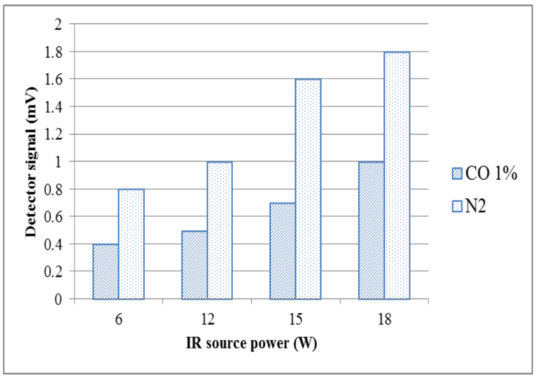

Fig. 7. Variations of detector signal with IR source power.

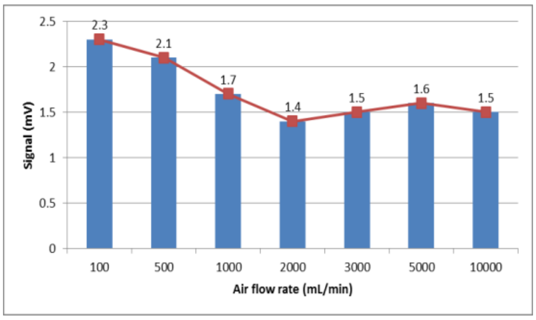

Fig. 8. The relationship between gas flow rate in the gas cell and detector signal.

In general, the NDIR sensor was designed with gas cell based on White cell method with 400 mm concave mirror. The chopper frequency was setup at 100 Hz. The gas flow rate was 1000 mL/min. An IR source with 20 W of power capacity and a gas cell temperature of 40 °C were selected in this research.

4 Conclusions

The IR intensity at the outlet window of the Herriott cell was higher than that of the White cell at the same waveguide length. It was found that the temperature of the gas cell did not affect the sensor's detectivity. In contrast, the higher IR intensity was, the higher the detectivity was. It was observed that the frequency of the chopper significantly had an impact on the detectivity of the sensor. With respect to one type of sensor, there was an optimal frequency of the chopper. In addition, the increase of the gas flow rate helped to improve the sensor's detectivity. However, when the flow rate was higher than 2000 mL/min, the detectivity was unchanged with the increase of the flow rate.

Acknowledgments. This research was supported by R&D Center for Green Patrol Technologies through the R&D for Global Top Environmental Technologies funded by Ministry of Environment, Republic of Korea (MOE).

References

1. Stuart, B.: Infrared Spectroscopy: Fundamentals and Applications. John Wiley & Sons, Ltd. (2004).
2. Wong, J.Y.:Non-dispersive infrared gas measurement. International Frequency Sensor Association Publishing (2012).
3. Mayrwoger, J., Reichl, W., Krutzler, C., Jakoby, B.: Measuring CO_2 concentration with a Fabry-Perot based bolometer using a glass plate as simple infrared filter. Sensor Actuat B-Chem 170, 143-147 (2012).

4. Sun, Y.W., Liu, W.Q., Zeng, Y., Wang, S.M., Huang, S.H., Xie, P.H., Xiao-Man, Y.: Water Vapor Interference Correction in a Non Dispersive Infrared Multi-Gas Analyzer. Chinese Phys Lett 28 (2011).
5. Sun, Y.W. , Zeng, Y. , Liu, W.Q., Xie, P.H., Chan, K.L, Li, X.X., Wang, S.M., Huang, S.H.: Cross-interference correction and simultaneous multi-gas analysis based on infrared absorption. Chinese Phys B 21 (2012).
6. Sklorz, A., Janssen, S., Lang, W.: Detection limit improvement for NDIR ethylene gas detectors using passive approaches. Sensor Actuat B-Chem, 175, 246-254 (2012).
7. White, J. U.: Long Optical Paths of Large Aperture Journal of the Optical Society of America Vol. 32, Issue 5, pp. 285-288 (1942).
8. Herriott, D. R. and Schulte, H. J.: Folded Optical Delay Lines. Applied Optics, Vol. 4, No. 8, pp. 883-889 (1965).
9. Crawley, L.H.: Application of non-dispersive infrared spectroscopy to the measurement of atmospheric. Master thesis, Univ. of Canterbury, New Zealand (2008).

