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Research paper

A Case Study on Relationship between Optical Path Length and Detection Limit of an NO Non-Dispersive Infrared Analyzer

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Abstract

Non-dispersive Infrared (NDIR) analyzer has been wildly used to monitor the emission of air pollutants from stationary sources. Lower detection limit of an NDIR analyzer depends on the optical path length of the IR beam. The relationship between the path length and the detection limit of a NO NDIR analyzer was investigated in this work. The path lengths of the analyzer were varied as 4.8, 8, 10.4 and 16 m. The measurement range of NO gas was 0 ~ 200 ppm. Gold coated mirrors were used to produce multi pathways for the NDIR gas cell based on the White cell principle. It was found that the detection limit of NO was 1.0 ppm at 16 m of the pathlength. In contrast, that of NO was 4.28 ppm at 4.8 m of the path length. The lower detection limit was inversely proportional to the optical path length. The optimal path length for NO gas in the range of 0 ~ 200 ppm was 16m.

Keywords: *Detection limit; Gas analyzer, NO; NDIR; Multi pathway*

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 for gas measurement targets the wavelength absorption in the infrared spectrum as a way to identify particular gases. NDIR technology is 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 (NO_x), nitrous oxide (N_2O), ammonia (NH_3), hydrogen chloride (HCl), hydrogen floride (HF) and methane (CH_4), etc (Stuart, 2004). A typical NDIR analyzer consists of a light source, a light chopper, a gas cell, and a detector (Wong, 2012c). One advantage of NDIR compared with other spectroscopy techniques is its low energy consumption. IR source with wavelengths in the range of 1 – 15 µm can operate at a lower temperature than other sources (Lillesand et al., 2004).

The technical foundation of NDIR gas analyzers is based on the Beer-Lambert law:

$$I = Io \times \exp(-kCL) \quad (1)$$

where Io is the initial radiation beam intensity, I is the beam intensity after traversing the gas to the detector, k is an absorption coefficient, C is a gas concentration, L is the sample optical path length defined typically by the effective sample chamber length of the analyzer. Based on the Beer-Lambert law, the detection limit of a target gas using the NDIR analyzer depends on the IR absorption of the target gas, the concentration of the target gas and the optical path length. In terms of stationary sources (e.g. incinerator, coal power plant), the concentrations of target gases are usually ppm level. Therefore, to improve the detection limit of the NDIR analyzer, the increase of the optical path length is the best way. Optical White cell has been widely used to make a multi path-way gas cell for the NDIR analyzer. The White cell consists of three concave mirrors that all have the same radius of curvature (see Fig. 1) (White, 1942). The centers of mirrors A and A′ is on the front surface of the mirror B. On the other hand, the center of the mirror B is on the halfway between other two mirrors. The path length depends on the radius of curvature and the position of center of A and A′ (White, 1942).

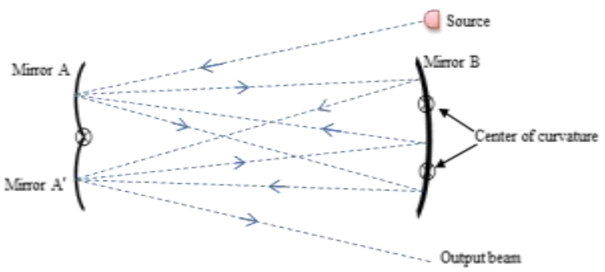

Figure 1: Diagram of White cell principle.

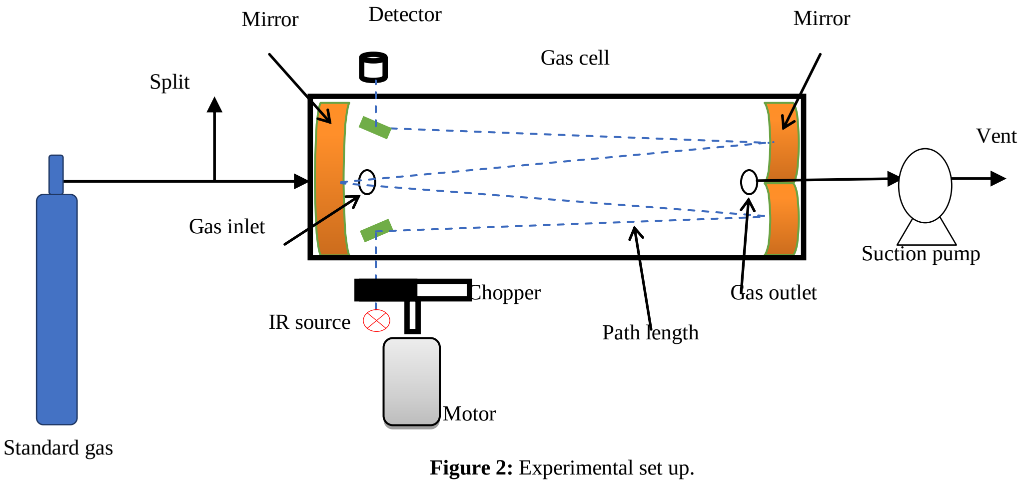

Figure 2: Experimental set up.

As mentioned above, the higher path length is the lower detection limit is. However, the increase of optical path length brings about the increase of the analyzer cost. Therefore, the optimal path length inventory data for each target gas is necessary. To the best of our knowledge, no research has been made to determine this issue. Hence, this research was conducted. The objective of our research is to determine the optimal path length of an NDIR analyzer for nitrogen monoxide (NO) with an emission range from 0 to 200 ppm.

2. Materials and Methods

An NDIR analyzer consisted of an 20W IR source (IR-Si253, Hawkeye Technologies Inc., USA), a pyroelectric detector (LMM-274-DILU, Infratec GmbH, Germany), a gas cell with gold coated mirrors and a chopper coupled with a motor (0729, Bodine Electric Co., USA). The experimental set up is presented in Fig. 2.

The gas flow rate was 1 L/min. The gas cell temperature was matained at 45°C. The room conditions were 25°C ± 1°C and RH = 40% ± 2%. The gas cell volume was 770 mL. The optical path lengths of gas cell were varied as 4.8, 8, 10.4 and 16m.

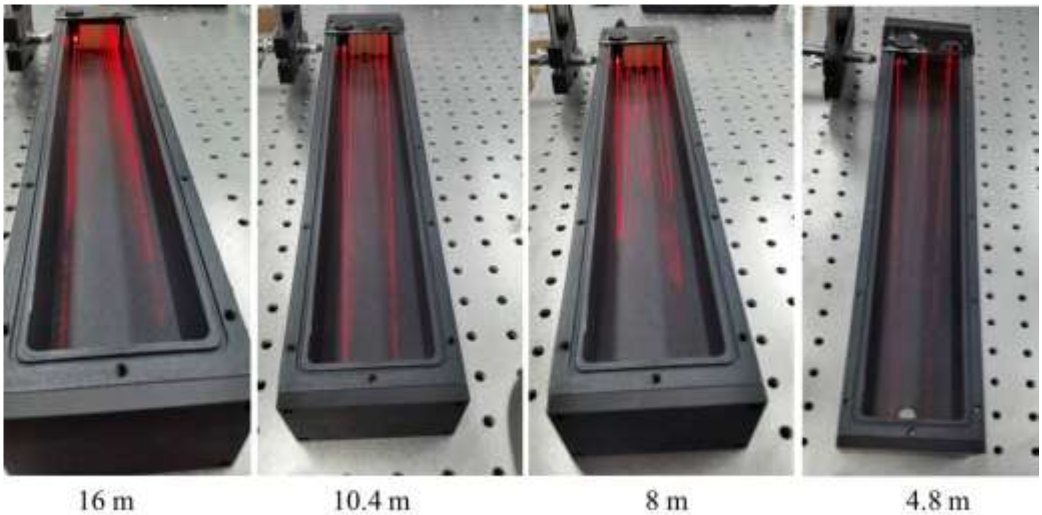

Figure 3: Patterns of different path lengths of the NDIR gas cell.

First, N2 (99.999%, DongA Ltd. Co., Republic of Korea) and NO standard gas (10, 100, 200 ppm, Rigas Co., Republic of Korea) were used to calibrate the analyzer. After calibration, N2 (99.999%, DongA Ltd. Co., Republic of Korea) was introduced into the analyzer to investigate the lower detection limit. The interval time for recording was 3 minutes and the repeativity was 20 times (MOE, 2016).

The lower detection limit (DL) was calculated using the following the equation (2).

$$DL(ppm) = 2 \times \sqrt{\frac{\sum_{i=1}^{20}(C_i)^2 - \frac{1}{20}(\sum_{i=1}^{20} C_i)^2}{19}} \quad (2)$$

Where Ci is the concentration displayed on the analyzer (ppm) at i time (i = 0 ~ 20) (MOE, 2016).

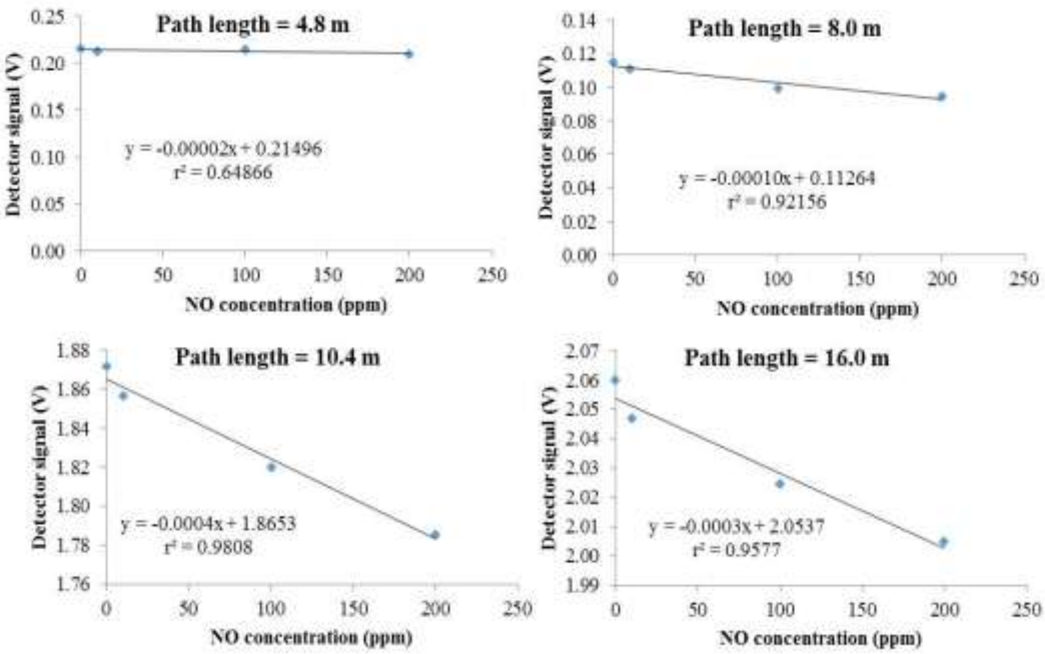

Figure 4: Variations of detector signals associated with NO concentrations and optical path lengths.

3. Results and Discussion

The different beam patterns of the gas cell are presented in Fig 3. The variation of output signals associated with NO concentrations and optical path lengths is depicted in Fig. 4. As shown in Fig. 4, the longer path length was, the more rapidly decreased the detector signal of NO was. It indicated that the different IR absorption capacity of NO was more significant at low IR intensity than that of at high IR intensity. Therefore, using longer path length is better in terms of IR absorption.

On the other hand, detector signals at 4.8 m of path length showed less consitant compared to other cases (r2 = 0.64866). The reason was that although the concentration of NO was varied from 10 to 200 ppm, the detector signals did not significantly change. Since the intensity of IR at 4.8m was very strong, the quantity IR absorption of NO at target concentration was not significant enough to change the detector signal. To overcome this problem, a more sensitive detector should be employed.

The lower detection limits related to path lengths is presented in Fig. 5. Based on the Korean national standard of NDIR analyzer approvement method, the detection limit must be 1% of full scale. It means the detection limit of the NDIR analyzer in this case should be lower than 2 ppm.

As shown in Fig. 5, at 16 m of path length, the detection limit was 1.0 ppm. Therefore, the optimal path length was 16 m in the range of 0 ~ 200 ppm of NO. It was also observed that the detection limit was decreased with the increase of the optical path length. This pattern was the same as that of the Beer-Lambert law. The other similar researches showed also the same results. Hodgkinson et al. (2013) developed a NDIR sensor for CO2. It was reported that to detect trace concentration of CO2, the path length of the NDIR sensor should be long as much as possible. However, manufacturing longer path length requires high technique and cost. Therefore, the path length should be considered with regard to detection range of target gas.

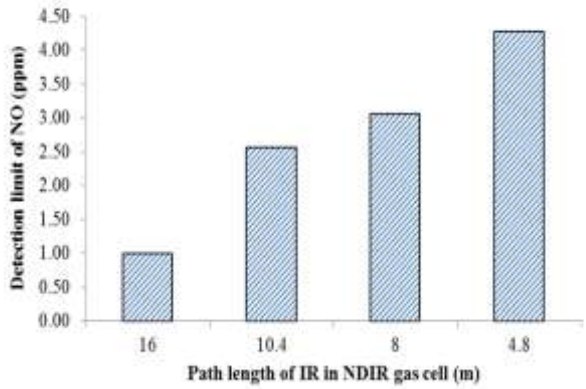

Figure 5: Relationship between detection limit of NO and optical path length of the gas cell.

4. Conclusions

The optimal path length of the NDIR analyzer for NO gas in the range of 0 ~ 200 ppm was investigated in this study. It was observed that the detection limit was inversely proportional to the path length. Moreover, the IR absorption of NO gas depended on the IR intensity of the IR beam. Due to low IR absorption of NO gas, strong IR intensity lead to less change of detector signal. Therefore, a practical optical pathlength coupled with a certain IR source power should be investigated. It was found that the optimal path length for NO in this work was 16 m. The optimal path length of other ranges of NO as well as that of other gases should be determined in the future works.

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