# Limitations of gas filter correlation: A case study on carbon monoxide non-dispersive infrared analyzer

Trieu-Vuong Dinh [a], Ji-Won Ahn [b], In-Young Choi [a], Kyu-Yong Song [a], Chang-Ho Chung [b], Jo-Chun Kim [a],*

[a] Department of Environmental Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-Gu, Seoul, 143-701, Republic of Korea
[b] International Climate and Environmental Research Center, Konkuk University, 120 Neungdong-ro, Gwangjin-Gu, Seoul, 143-701, Republic of Korea

## ARTICLE INFO

## ABSTRACT

Two commercial Non-Dispersive Infrared (NDIR) analyzers for carbon monoxide (CO) coupled with a gas filter correlation (GFC) were used to investigate the interference effects by other gases except for CO. A stack level of particular gases including $CO_2$, NO, $NO_2$, $SO_2$, and $H_2O$ (g) were mixed with CO to introduce into the analyzers. It was found that the measurement error of two analyzers were the lowest at 50 ppm and 70 ppm of CO, respectively. Moreover, the increase of concentrations of the interfering gases ($CO_2$, NO, $NO_2$, and $SO_2$) induced an interfering effect on the performance of two analyzers. This indicated that the GFC could not cover the entire range of interfering gases. In a special case, the accuracy of the analyzers with humid mixed gases was better than that with dry mixed gases due to the absorption of water-soluble gases by condensate. However, this accuracy was only apparent with respect to low solubility of analytical target gas such as CO. The solubility of the target gas might dramatically reduce the accuracy of the analyzer.

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## 1. Introduction

Most air pollutants emitted from a stack (e.g. CO, NO, $NO_2$, $CO_2$, $SO_2$, HCl, and $NH_3$) can absorb infrared (IR) spectra at mid-wavelength. Moreover, an IR source consumes less energy than other light sources. Therefore, non-dispersive infrared (NDIR) analyzers have been popularly used to monitor the emission of air pollutants from a stationary source. Other advantages of the NDIR analyzer include its low cost, high sensitivity, fast responsiveness and consistent operation. However, the absorption spectra of one gas could interfere with that of another gas (e.g. CO with $CO_2$ and $H_2O$) [1]. To overcome this issue, the gas filter correlation (GFC) technique has been widely employed in infrared spectroscopy analyzers, particularly in the NDIR analyzer [2–6].

A GFC is a gas cell which is separated into two chambers, whereby one half of the cell (so-called specifying cell) contains the specified gas at a certain concentration (i.e. analytical target gas) and the other half (so-called reference cell) contains the transparent gas (e.g. $N_2$, Ar) (Fig. 1). Theoretically, when IR radiation from a source passes through the GFC, the radiation will be strongly absorbed in the specifying cell. Therefore, it is not absorbed further in the gas cell by the target gas. However, if interfering gases exist, the radiation would be attenuated. In contrast, after passing the reference cell, the IR radiation is strongly attenuated in the gas cell due to the absorption of the target gas and the interfering gases. An IR detector will obtain all these signals. After subtracting the signal of interfering gases, the accuracy of the analytical results will be increased. The GFC also helps to increase the sensitivity and selectivity of the NDIR analyzer due to the introduction of a large amount of sample gas. Furthermore, the advantages of the GFC are its high degree of multiplexing and spectral resolution [4]. However, the GFC is only effective with gases which have strong IR spectral absorption at low concentration [6]. Moreover, its effectiveness also depends on the width and shape of the IR beam [4].

In terms of industrial stationary sources, the concentration of air pollutants from the stack is high, especially in $CO_2$ and $H_2O$ (Table 1). Therefore, the accuracy of the NDIR analyzer would be still affected by the interference of $CO_2$ and $H_2O$. Few studies on this issue have been carried out. Nowadays, a commercial NDIR analyzer is usually coupled with the GFC. The analyzer is also calibrated with interfering gases. However, high concentration of some air pollutants concerned and variation of emission by time might affect the analyzer performance.

Accordingly, in this study, limitations of NDIR analyzers for carbon monoxide employing the GFC were determined when the

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* Corresponding author at: Dept. of Environmental Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-Gu, Seoul, 143-701, Republic of Korea.
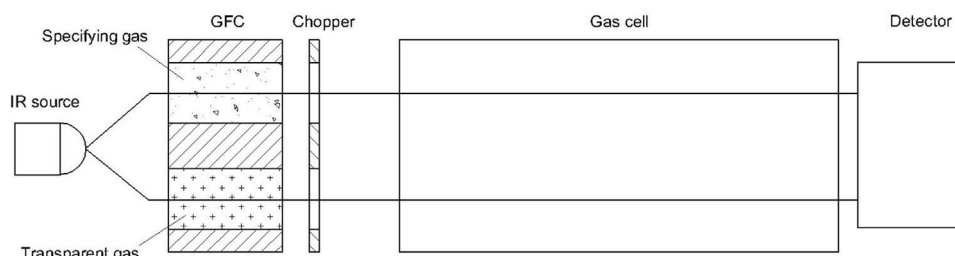*E-mail addresses:* sonys@kaeri.re.kr, jckim@konkuk.ac.kr (J.-C. Kim).

**Fig. 1.** Diagram of an NDIR coupled with a GFC.

**Table 1**
Inventory data of several air pollutants emitted from various stacks.

| Emission source | Temp. °C | $H_2O$ g/m$^3$ | CO % | $CO_2$ % | $SO_2$ ppm | NO ppm | $NO_2$ % | $NH_3$ ppm | References |
|---|---|---|---|---|---|---|---|---|---|
| Blast furnace | 72.0 | 35.6 | – | – | 6.3 | – | – | – | [7] |
| Basic oxygen furnace | 54.0 | 38.2 | – | – | – | – | – | – | [7] |
| Coke oven | 79.0 | 31.8 | – | – | 8.5 | – | – | – | [7] |
|  | 55–80 | – | 0.04–0.09 | 7.3–15.4 | 78–303 | 118–157 | 0.4–1 | 0.3–136 | [8] |
| Electric arc furnace | 86.7 | 25.6 | – | – | 20 | – | – | – | [7] |
| Heavy oil plant | 247 | 30.8 | – | – | 71 | – | – | – | [7] |
| Power plant | 177 | 42.4 | – | – | 320 | – | – | – | [7] |
| Cement (drying) | 103 | 113.2 | – | – | 4.1 | – | – | – | [7] |
|  | – | – | 0.004 | 4–25 | – | – | – | – | [9] |
| Cement (pryoprcessing) | 142 | 18.5 | – | – | – | – | – | – | [7] |
| Coal combustion | – | 30–45 | 0.002 | 15–16 | 1000 | 500 | – | – | [10] |

analyzers were performed under a stack condition. Carbon monoxide was selected because it has low spectral absorption compared to other emission gases as well as low concentration which needs an analyzer with a high sensitivity.

## 2. Experimental methods

### 2.1. Apparatus

An NDIR analyzer for CO gas (Serinus 30, Ecotech, Australia; analyzer 1) and another NDIR analyzer for CO gas (GP-300, Kentek Ltd., Republic of Korea; analyzer 2) were used. The lower detectable limit of the analyzers was <0.05 ppm. The noise was 0.1% of the concentration reading. The sample flow rate was 1 L/min. The gas cell of the analyzer was maintained at 50 °C of temperature to prevent the condensation of water vapor. The operation range of the analyzer 1 was 0–200 ppm and that of the analyzer 2 was 0–100 ppm. A gas calibrator (146i, Thermo Scientific, USA) was used to dilute standard gases. Humidity was generated using a heated water bubble bottle and was determined using a humidity sensor (645, Testo Inc., USA).

### 2.2. Materials

Nitrogen ($N_2$) (99.999%, DongA Ltd., Korea) and CO standard gas (99.95%, REGAS, Republic of Korea) were used to calibrate the NDIR sensor. Zero air (99.999%, DongA Ltd., Republic of Korea), NO (1%, AirKorea Ltd., Republic of Korea), $NO_2$ (1%, AirKorea Ltd., Republic of Korea), and $SO_2$ (1%, AirKorea Ltd., Republic of Korea) were used to carry out the experiments.

### 2.3. Experimental procedure

The experimental setup is presented in Fig. 2. First, two NDIR analyzers were calibrated with zero gas ($N_2$) and span (i.e. analyzer 1: 180 ppm of CO; analyzer 2: 80 ppm of CO), as recommended by the manufacturer. Then, the response factors of the analyzers were determined using CO standard gas diluted with zero air varied from
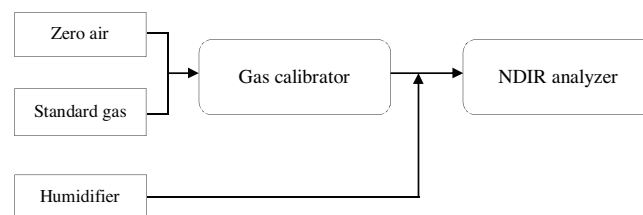


**Fig. 2.** A schematic of experimental setup.

0.5 to 250 ppm and 0.5–100, respectively. To investigate the effects of other emission gases on CO, CO was mixed with other gases to create a solution (Table 2) and then introduced into the analyzers. In case of the analyzer 1, $CO_2$ concentrations were varied from 1% to 30%. NO and $NO_2$ concentrations were also varied as 1, 50, 100, 250, 500, and 1000 ppm. $SO_2$ concentrations were varied as 50, 100, 200, 400, 500, and 1000 ppm. In case of the analyzer 2, $CO_2$ concentrations were varied from 0.5% to 40%. $SO_2$, NO, and $NO_2$ concentrations were varied 1, 50, 100, 250, 500, 1000 ppm. The various amount of water vapor was introduced into two analyzers as 5, 10, 15, 20, 30, 40, and 50 g/m$^3$. The experimental duration was 30 min and was performed in triplicate. The experiment was conducted at room temperature (25 °C).

STATGRAPHICS Centurion XV software with ver. 15.2.05 (Statpoint Technologies Inc., Warrenton, VA USA) was used to depict the Box-Whisker plot of the results.

## 3. Results and discussion

### 3.1. Accuracy of the analyzer

Various concentrations of CO were introduced into both analyzers to investigate their performance. It was found that both of the analyzers showed good performance because the values were similar to those of the standard gases (r$^2$ = 0.999) (Fig. 3). Although the measurement precision of the sensor was good (RPD < 1%) in general within the operation range, the best response factor was