Carbon Monoxide Sensor Based on Non-Dispersive Infrared Principle

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Abstract. Carbon monoxide (CO) is one of the toxic air pollution produced in incomplete combustion of carbon-containing fuels. At a certain threshold of concentration, this gas can harm the environments and affect the human health. Unfortunately, it cannot be detected by humans. In this study, CO gas detection has been designed and constructed using the principle of Non-Dispersive Infrared (NDIR). An incandescent light bulb is used to provide infrared source. An optical filter based on interferometry with a bandpass of about 4.63 μm is used to pass the light which corresponds to the CO gas absorption. The TPS 334 thermopile sensor is used to measure light intensity after gas absorption. The built-in RTD in the thermopile is involved to compensate the results of the gas concentration measurement. The experimental result shows that this NDIR sensor can measure CO gas concentration with a sensitivity of about 7 mV / ppm.

Keywords – Carbon monoxide, Non-Dispersive Infrared sensor, Optical filter

1. Introduction

In Indonesia, the air pollutant produced by gas emission of vehicles has reached 70-80% of total air pollutant emission. The increasing number of vehicles make a significant contributor to rising up the concentration of pollutant gases, e.g. carbon monoxide (CO) and carbon dioxide (CO$_2$) [1]. The concentration of gas must be considered that it can affect living things including human health [2]. Gas pollutants are also discussed in forums both globally and locally because they are an important problem in society [3]. The World Health Organization has issued guidelines for CO levels in the air, to prevent COHb levels in human blood from rising above 2.5%. The level of 2–20% concentration of COHb led to equivocal effects on visual perception, audition, motor and sensorimotor performance, vigilance, and other measures of neuro behavioural performance [4].

Currently, there are many general techniques or methods for detecting gases including CO gas, such as electrochemical cells, catalytic sensors, and photoionization detectors [5]. However, these techniques require special handling regarding their operational procedures, high costs and limited detection range.

In this study, we have constructed CO gas detection using the principle of Non-Dispersive Infrared (NDIR). The characteristic of light absorption by CO gas at certain wavelength shown in figure 1. Therefore, an optical band-pass filter that appropriate with the CO gas characteristics must be applied to this method. Figure 2 shows an optical filter based on the principle of interferometry, which the difference in the path length of the light beams is expressed in equation (1).
Figure 1. The absorption spectrum of CO gas.

Figure 2. The interference of light in plane parallel plate.

\[
\Lambda = 2n_f d \cos \theta_t
\]  \hspace{1cm} (1)

where, \( \Lambda \) is the difference in the length of the beam path reflected from the side of the plane-parallel plate which corresponds to the wavelength of the light for constructive interference. In the NDIR sensor, the infrared light intensity will be absorbed by gas molecules that meet the Lambert-Beer Law expressed as:

\[
I = I_o \cdot e^{-kCL}
\]  \hspace{1cm} (2)

where, \( I \) is the light intensity after passing through the gas sample, \( I_o \) is the intensity of the light source, \( k \) is the absorption coefficient, \( C \) is the gas concentration, \( L \) is the optical path length of the sample chamber. The NDIR sensor could be operated at low temperature [6], and possible to have small-compact configuration [7]. Based on its operating principle, NDIR has a good selectivity to detect certain gas if it is equipped with specific optical filter.
2. Method
The infrared source comes from an incandescent light bulb, which has a maximum voltage of 2.5 volts and a current of 300 mA. These light bulbs are powered by current sources based on the LM 317 regulator circuit. The current source is needed in order to provide constant light intensity. Figure 3 shows the gas collecting process and the NDIR sensor diagram. The gas sample for the experiment is the exhaust gas from the gasoline engine collected in the sample bag. Paper filter is used to remove other smoke molecules to get the desired gas sample.

The sample chamber is made of aluminum tube with a length of 30 cm and a width of 2.5 cm which is isolated from external light interference. The optical filter used in this experiment is an interferometric filter with bandpass of around 4.63 μm which corresponds to the CO gas absorption. The optical filter is situated in front of the infrared detector of the TPS 334 thermopile sensor to reject other wavelengths as shown in figure 4. Figure 5 depicts block diagram of the NDIR sensor system. Because the output signal produced by the infrared detector is relatively small, an OP07-based linear amplifier that has a voltage gain of 1000 is applied in this experiment. The analog signal sensor is then converted to digital value by analog-to-digital conversion (ADC) which is internally available on the Arduino DUE microcontroller and sent to a personal computer via a USB port. The NDIR sensor system for detection of carbon monoxide is shown in figure 6. For calibration purposes, the CO 7701 model produced by AZ Instrument is used to determine the concentration of gas samples. The clean air coming out of the silica gel filter is transferred to the sensor chamber in a few minutes to get the baseline value [11,12]. All experiments were carried out in the laboratory at room temperature [13-15].

![Figure 3. (a) Gas collecting process. (b) The NDIR sensor diagram.](image)

![Figure 4. The NDIR sensor used in the experiments.](image)
3. Result and Discussion
The type of detector used in this experiment depends on the ambient temperature which can affect the variation of cold junction in the thermopile. Figure 7 shows the effect of the NDIR sensor on the temperature around the chamber sensor. Therefore, the built-in Resistance Temperature Detector (RTD) in the thermopile must be involved to compensate so that the results of the gas concentration measurement are not affected by environmental changes. Figure 8 shows the effect of the RTD on the temperature changes. To produce an appropriate value, this built-in RTD is excited by an external power source. Both types of the detectors should be adjusted in order to have similar sensitivity to the temperature changes. In general, the NDIR sensor value is a thermopile sensor response which is subtracted by RTD responses with certain weight. Figure 9 shows the NDIR sensor response to CO Gas concentration, while figure 10 shows the NDIR sensor response after being subtracted by its
The relationship between the NDIR sensor voltage, and the CO gas concentration is expressed as:

\[ y = 7.135 \ln(x) - 1.573 \]  

(3)

where, \( y \) is the NDIR sensor voltage (mV), and \( x \) is the CO concentration (ppm).

Figure 7. NDIR sensor response to temperature changes.

Figure 8. The RTD resistance to temperature changes.

Figure 9. The NDIR sensor response to CO gas concentration.
4. Conclusion
In this study, CO gas detection has been designed and constructed using the principle of NDIR. An incandescent light bulb is used to provide infrared source. An optical filter based on interferometry with a bandpass of about 4.63 μm is used to pass the light which corresponds to the CO gas absorption. The TPS 334 thermopile sensor is used to measure light intensity after gas absorption. The built-in RTD in the thermopile is involved to compensate the results of the gas concentration measurement. The experimental result shows that this NDIR sensor can measure CO gas concentration with a sensitivity of about 7 mV / ppm.

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