Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile

By

Karen Kaye M. Alix
Patrick Wesley U. Chan
Christian Ramir P. Lazatin
Ma. Giovyline S. Rañoa

A Thesis Report Submitted to the School of EECE
in Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Computer Engineering

Mapúa Institute of Technology
June 2013

APPROVAL SHEET

This is to certify that we have supervised the preparation of and read the thesis paper prepared by **Karen Kaye M. Alix, Patrick Wesley U. Chan, Christian Ramir P. Lazatin,** and **Ma. Giovyline S. Rañoa** entitled **Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile** and that the said paper has been submitted for final examination by the Oral Examination Committee.

Voltaire B. De Leon
Academe Adviser

Rafael G. Maramba
Thesis Adviser

As members of the Oral Examination Committee, we certify that we have examined this paper and hereby recommend that it be accepted as fulfillment of the thesis requirement for the Degree **Bachelor of Science in Computer Engineering (major).**

Analyn N. Yumang
Panel Member 1

Jose B. Lazaro Jr.
Panel Member 2

Joshua B. Cuesta
Committee Chair

This thesis is hereby approved and accepted by the School of Graduate Studies as fulfillment of the thesis requirement for the Degree **Bachelor of Science in Computer Engineering (major).**

Dr. Felicito S. Caluyo
Dean, School of EECE

ACKNOWLEDGEMENT

First and foremost the researchers would like to thank the God Almighty for giving us wisdom and guidance in the completion of this thesis report.

This project would not have been possible without the support of many people. The group wishes to express their gratitude to their thesis instructors, Prof. Ayra G. Panganiban and Prof. Voltaire B. De Leon, who were unselfishly helpful and offered invaluable assistance, support and guidance.

We also extend our special thanks to our adviser, Engr. Rafael G. Maramba, whose encouragement, guidance and support from the preliminary to the concluding level enabled us to develop an understanding of the subject.

Finally, we would like to thank our parents and siblings for supporting, providing financial means and encouraging us to finish this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Carbon monoxide (CO) gas is a compound produced by incomplete combustion of various carbon-based fuels and substances. The slow accumulation of this poisonous gas can cause headaches, nausea, vomiting, vertigo and confusion which are harmful for passengers' safety and environmental protection. The purpose of this study was to develop a carbon monoxide monitoring system for automobiles. The system includes a carbon monoxide detector which is capable of measuring concentration of the gas when it reaches the predetermined levels; the alarm system would notify the passenger/s and also the nearby people, at the same time it would prevent the hazardous gas to spread inside the vehicle. As a way for the system to save the passenger, the device will activate an exhaust fan connected inside the vehicle then it would be directed to a modified catalytic converter to release the trapped gas passing through the chemical reaction incorporating the soda lime for the soda lime air purification process.

Keywords: carbon monoxide monitoring system, catalytic converter, soda lime, alarm system, air purification process

Chapter 1

INTRODUCTION

Carbonous oxide or commonly known as carbon monoxide (CO) is a colorless, odorless and tasteless gas that is fractionally lighter than air. It is a by-product of incomplete combustion of fossil fuels, such as those combustion fumes made by cars and trucks, lamps, stoves, gas ranges and heating systems. The carbon monoxide from these fumes can accumulate in places, as a result of poor installation, poor maintenance, failure or damage of an appliance in service, when the fuel is not burned properly, or when rooms are poorly ventilated and don't have a good flow of fresh air for the CO to escape. These results can make the CO easily rise to potentially lethal and poisonous health risk. Since carbon monoxide is colorless, odorless, tasteless and initially non-irritating, it becomes very difficult for people to detect. Exposures to this toxic gas may lead to symptoms of mild acute poisoning including confusion, vertigo, headaches, dizziness and flu-like effects; larger exposures can lead to significant toxicity of the central nervous system and heart, and even death. Carbon monoxide can also have severe effects on the fetus of a pregnant woman. Prolonged exposure to low levels of carbon monoxide can lead to depression, confusion, and memory loss.

CO, one of the major causes of respiratory disease, is also addressed as the "Silent Killer". It is the leading cause of accidental poisoning deaths in America. The US Center for Disease Control estimates that carbon monoxide poisoning claims nearly 500 lives, and causes more than 15,000 visits to hospital emergency departments annually.

Nowadays, carbon monoxide monitoring and alert systems are commercially available in the market. Most of these devices are installed at home/buildings and are also able to detect other dangerous gases in air while other systems are used in the mining industry. Although there are many variations of the carbon monoxide system, almost all of these are designed for buildings and home use only to detect the build up of poisonous gas in the air and notify the people inside.

This study aims to develop a system with proper application of system-connected carbon monoxide detectors that can monitor carbon monoxide concentration inside automobiles and convert this harmful gas into breathable air. The specific objectives of this study are to:

a) Integrate a catalytic converter with the use of soda lime.
b) Convert carbon monoxide into a breathable gas with implementation of ATMega168 microprocessor for the system's operation.

The study would significantly impart endeavor in assuring the health and safety of both the people and the environment. Since carbon monoxide poisoning and air pollution is a universal problem that the world is facing, this study would definitely contribute to the decrease of the cause of respiratory diseases and also the reduction of the emission of air pollutants in the environment. The study would also provide additional information by proposing a better way of detecting the amount of carbon monoxide entering the vehicle that possessed significant performance. Lastly, this research will be a helpful reference for other related studies in the future.

The study entitled “Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile” deals with the selected automobile such as cars and vans. The separation of the power supply unit of device from the vehicle’s power supply which is tapped to the automobile’s battery makes it more reliable in terms of performing the monitoring and releasing of the toxic gas, while the soda lime air purification process relies on the power of the vehicle since it requires the modified catalytic converter to function together with vehicle’s power supply. The device is dependent on the amount of soda lime for the air purification process. The soda lime air purification process would take place if the quantity of carbon monoxide inside the automobile reaches the standard amount, however if the quantity is less than the standard, the system would remain idle.

Chapter 2

REVIEW OF RELATED LITERATURE

According to one of the Philippines' news site, Inquirer.net, last July 5, 2010, a teenage couple was found dead inside a car for the sole reason of carbon monoxide poisoning. Investigators said the victims died of carbon monoxide suffocation after they inhaled the exhaust fumes coming from the car. It was told that the moment the couple was found dead; the car's engine and air-conditioning were running. Chief Inspector Benjamin Elenzano Jr. of the Quezon City Police District's homicide section said that, "because of the enclosed space of the garage and the fact that the car exhaust was facing a wall, the carbon monoxide accumulated and seeped into the vehicle."

Carbon Monoxide

Carbon monoxide (CO), also called carbonous oxide, is a colorless, odorless, and tasteless gas that is slightly lighter than air. Carbon monoxide is formed by the incomplete combustion of materials containing carbon and can be produced by virtually anything that burns. However, it is short lived and spatially variable in the atmosphere, since it combines with oxygen to form carbon dioxide and ozone.

It is a by-product of combustion, present whenever fuel is burned without enough air (oxygen). It is commonly produced by home appliances such as gas or oil furnaces, gas refrigerators, gas clothes dryers, gas ranges, gas water heaters, fireplaces, charcoal grills, and wood burning stoves. Fumes from automobiles and gas-powered lawn mowers may also contain carbon monoxide and can enter a home through walls or doorways if an engine is left running in an attached garage. Other sources include industrial processes, cigars, smoldering fires, etc.

Carbon Monoxide Poisoning

Carbon monoxide can be toxic to humans and animals when encountered in higher concentrations, although it is also produced in normal animal metabolism in low quantities, and is thought to have some normal biological functions. When you inhale carbon monoxide, it can cause brain damage, suffocation or death. Because you cannot see, smell or taste this deadly gas, poisoning can happen to anyone, anytime, anywhere. Everyone is at risk but pregnant women, young children, senior citizens and people with heart and lung problems are at greater risk. If your home is well sealed or not well ventilated, the levels of carbon monoxide in the air may easily rise to deadly levels.

Carbon Monoxide Reaction

Carbon monoxide is flammable. Mixtures of carbon monoxide and air in the flammable range will ignite if a flame or a spark is present. Flammable mixtures containing carbon monoxide and other gases can be ignited easily by heated surfaces, open flames and even by the burning tip of a cigarette. The serious nature of the flammability hazard is reflected in the extensive flammable range of carbon monoxide in air (see Table 1 on page 6).

Table 1: Physical Properties of Carbon Monoxide

Physical Properties		
Melting (freezing point)	-205°C	-337°F
Boiling Point (normal atmospheric pressure)	-192°C	-313°F
Vapor Density (air =1)	0.9678	
Flammability		
Flammable Range (in air by volume)	12.5 to 74%	
Auto-ignition Temperature	610°C	1130°F

Courtesy of Industrial Accident Prevention Association 2008

Carbon monoxide is chemically reactive at temperatures over 90 °C. This reactivity and chemical incompatibility can be of great concern in laboratories and process operations where compressed carbon monoxide is present (see Table 2).

Table 2: Incompatibility of Materials

Materials to avoid
• Metal oxides (e.g. iron oxide, nickel oxide) – reduced to lower metal oxides, metal or metal carbides at elevated temperatures.
• Some heavy metals (e.g. nickel, iron, chromium) – formation of explosive metal carbonyls.
• Alkali and alkaline earth metals (e.g. sodium, potassium, magnesium) – react to produce salts.
• Aluminum powder – ignition can occur.
• Iodine heptafluoride – ignition can occur.
• Sulfur – carbon monoxide reacts slowly with the liquid and rapidly with the vapor to give carbonyl sulfide.
• Chlorine – can form phosgene in the presence of light or a charcoal catalyst.
• Bromine – can form carbonyl bromide in the presence of light or a charcoal catalyst.
• Bromine trifluoride, bromine pentafluoride, chlorine dioxide or peroodisulfuryldifluoride –react explosively.
• Oxidizing materials – increased risk of fire and explosion.

Courtesy of Industrial Accident Prevention Association 2008

Physiological Effects of Carbon Monoxide

Most of the time, when there is poisoning of carbon monoxide on a person's vital system, symptoms are likely to be compared equally to common illnesses including tiredness, headaches, dizziness, nausea or vomiting, and shortness of breath. The skin may also turn pink or red in response to rising blood pressure.

The amount of CO which the blood absorbs depends on two things: how much CO is in the air and the time of the exposure. Table 3 on the next page shows the different effects of CO poisoning on humans based on the amount of CO in air and the length of exposure. Adverse effects of CO on humans are reduced by periods of breathing fresh air. The degree of recovery depends on the number and length of those periods.

Other factors that determine the effect carbon monoxide has on the body are:

- Age
  - Fetuses (Maternal cigarette smoking is a major source of exposure.)
  - Infants
  - Older adults
- Individual susceptibility
- Smoker versus non-smoker (smokers have higher levels of carbon monoxide in their blood and may experience harmful effects at lower concentrations)
- Gender: death rates higher in males
- Blood, heart, or lung conditions

Table 3: Physiological Effects of CO poisoning

Parts per Million	Time of Exposure	Response
50		Threshold limit, no apparent toxic symptoms
100	Several Hours	No symptoms for long periods
200	2-3 hours	Possible headache
400	1-2 hours	Frontal headache and nausea
800	45 minutes	Headache, dizziness and nausea
800	2 hours	Collapse and possible unconsciousness
1600	20 minutes	Headache, dizziness and nausea
1600	2 hours	Collapse, unconsciousness, possible death
3200	5-10 minutes	Headache and dizziness
3200	10-15 minutes	Unconsciousness and possible death
6400	1-2 minutes	Headache and dizziness
6400	0-15 minutes	Unconsciousness and possible death
12800	Immediate	Unconsciousness
12800	1-3 minutes	Danger of death

Courtesy ofhttp://www.carbon monoxide.ie/htm/poisoning.htm

Carbon Monoxide Statistics

Unintentional CO exposure accounts for an estimated 15,000 emergency department visits and 500 unintentional deaths in the United States each year. The most recent state-level estimates of CO-related deaths were described in 1991 for the years 1979-1988. Using the most recent mortality data available, this report updates national and state-specific unintentional, non-fire-related CO mortality rates and describes the demographic, seasonal, and geographic patterns for 1999-2004 (see Table 4). During this period, an average of 439 persons died annually from unintentional, non-fire-related CO poisoning, and the national average annual death rate was 1.5 per million persons. However, rates varied by demographic subgroup, month of the year, and state. Rates were highest among adults aged ≥65 years, men, non-Hispanic whites, and non-Hispanic blacks. The average number of deaths was highest during January.

Table 4: Unintentional, non-fire-related deaths from carbon monoxide (CO) poisoning, in United States of America from 1999 to 2004

Characteristic	Total deaths No.	(%)	6-year average annual crude rate†	6-year average annual rate†	(95% CI§)
Total	**2,631**	**(100)**	**1.53**	**1.53**	**(1.47–1.59)**
Age group (yrs)					
0–4	**52**	**(2)**	0.45	—	—
5–14	**83**	**(3)**	0.33	—	—
15–24	**256**	**(10)**	1.06	—	—
25–34	**322**	**(12)**	1.35	—	—
35–44	**505**	**(19)**	1.87	—	—
45–54	**472**	**(18)**	2.00	—	—
55–64	**314**	**(12)**	2.00	—	—
≥65	**628**	**(24)**	2.13	—	—
Sex					
Male	**1,958**	**(74)**	2.32	2.41	(2.30–2.52)
Female	**673**	**(6)**	0.77	0.74	(0.68–0.79)
Race/Ethnicity¶					
White, non-Hispanic	**1,941**	**(74)**	1.65	1.54	(1.48–1.61)
Black, non-Hispanic	**305**	**(11)**	1.46	1.64	(1.45–1.83)
Other, non-Hispanic	**97**	**(4)**	0.98	1.01	(0.80–1.22)
Hispanic	**279**	**(11)**	1.25	1.31	(1.14–1.48)

* Deaths coded with *International Classification of Disease, Tenth Revision* codes T58 and X47, excluding X00–X09, X76, X97, Y26, and Y17.
† Average age-adjusted rate per 1 million persons.
§ Confidence interval.
¶ Records in which ethnicity was unknown or missing were excluded from analysis (n = 9).

Courtesy of http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5733a2.htm

Carbon Monoxide on the Car

Motorists have expressed great concern over the recent incidents of deaths inside automobiles. During the past years, a number of people have been found dead inside their cars. The culprit is a silent but lethal gas known as carbon monoxide (CO).

Emissions of CO from vehicles are caused by defective exhaust system, defective emission system, and poorly tuned engine. According to Greg Valdepenas, a chief mechanic, a leak in the exhaust system allows the escape of CO before it is converted to nontoxic carbon dioxide (CO,) in the catalytic converter. The leaking CO can enter through the holes inside the car or open windows or doors. Old and dirty vehicles emit the highest concentrations of CO and can leave a cloud of CO whenever it is used. Running through the plume can cause health hazard to people. Smoke belching vehicles also contribute to CO emission, he added.

Carbon Monoxide to Carbon Dioxide

A catalytic converter is a device incorporated into the exhaust system of an automobile that reduces the amount of pollutants in the automobile's exhaust gases. The catalytic converter is used to complete the oxidation process for hydrocarbon (HC) and carbon monoxide (CO), in addition to reducing oxides of nitrogen (NO) back to simple nitrogen and carbon dioxide. Toyota Motor Sales, U.S.A., Inc. makes use of a modern catalytic converter also known as a three-way catalytic converter; the reason for this is that the “3-way” refers to the 3 harmful compounds that it helps reduce (HC, CO & NO). The basic materials of the three-way catalytic converter are platinum (Pt), rhodium (Rh) and palladium (Pd), and a thin coat of their mixture is applied onto a honeycomb or porous ceramic (carrier). Platinum and palladium are the oxidizing catalysts for HC and CO;

Rhodium is the reducing catalyst for NOx while Cerium promotes oxygen storage to improve oxidation efficiency.

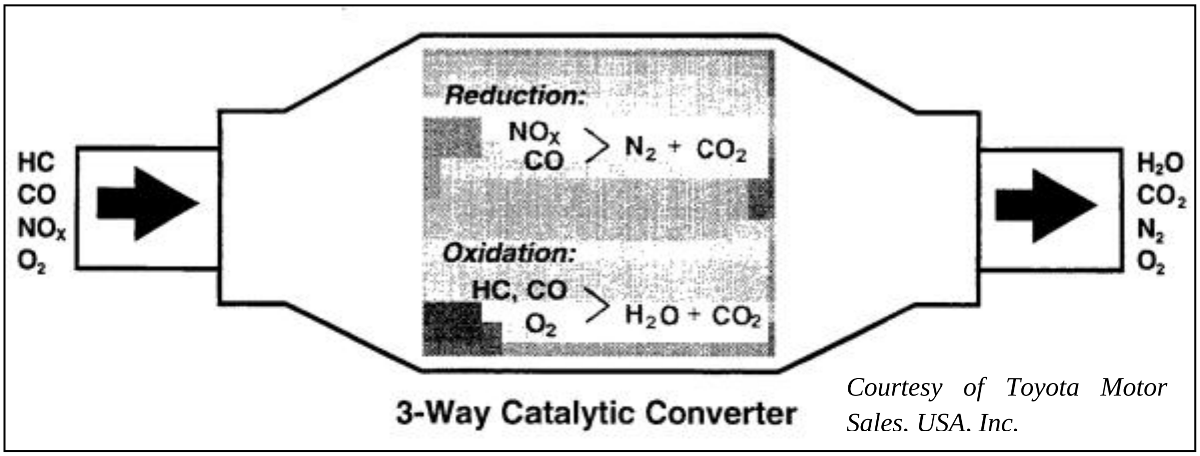


Figure 1: Chemical reaction inside a 3-way catalytic converter

Figure 1 shows the reaction of oxidation and reduction inside the 3-way catalytic converter. As engine exhaust gases flow through the converter passageways, they contact the coated surface which initiates the catalytic process. As exhaust and catalyst temperatures rise, the following reaction occurs:

- Oxides of nitrogen (NO_x) are reduced into simple nitrogen (N_2) and carbon dioxide (CO_2)
- Hydrocarbons (HC) and carbon monoxide (CO) are oxidized to create water (H_2O) and carbon dioxide (CO_2)

<u>The Combustion Process</u>

As stated by the U.S. Environmental Protection Agency Office of Mobile Sources, gasoline and diesel fuels are mixtures of hydrocarbons, compounds which contain hydrogen and carbon atoms. In a “perfect” engine, oxygen in the air would convert all the hydrogen in the fuel to water and all the carbon in the fuel to carbon dioxide. Nitrogen in the air would remain unaffected. In reality, the combustion process cannot be "perfect," and automotive engines emit several types of pollutants.

<u>Perfect Combustion</u>

FUEL (hydrocarbons) + AIR (oxygen and nitrogen)

CARBON DIOXIDE + water + unaffected nitrogen

<u>Typical Engine Combustion</u>

FUEL + AIR UNBURNED HYDROCARBONS + NITROGEN OXIDES + CARBON MONOXIDE + CARBON DIOXIDE + water

Soda Lime

According to a technical article by Molecular Products Ltd. company entitled "An Introduction to Sofnolime", soda lime is an absorbent used for removal of carbon dioxide mainly from breathable gases, in medical, military and safety applications. Sofnolime is Molecular Products' brand name for soda lime. The gas is passed through the absorber and the CO2 is removed by a water mediated base catalysed chemical reaction (Figure 2), converting the CO2 to calcium carbonate and H2O which is retained within the absorber. The strong base, NaOH, is not used up but acts as a catalyst.

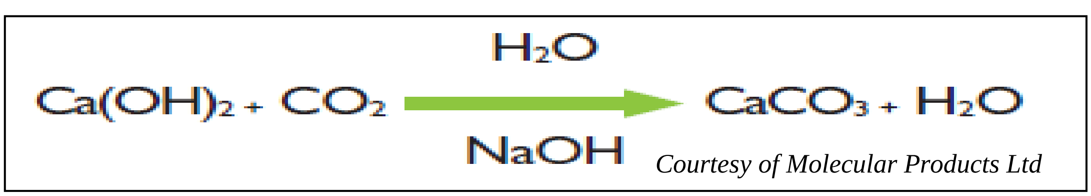


Figure 2: Chemical reaction of Soda Lime

As shown in Figure 3, the absorber will have a finite life based on the quantity of Sofnolime contained and the level of CO2 within the treated gas. The absorber will remove all of the CO2 (if appropriately sized for the application) and once the Sofnolime is consumed, CO2 breakthrough will occur and the CO2 level in the exiting gas stream begins to increase.

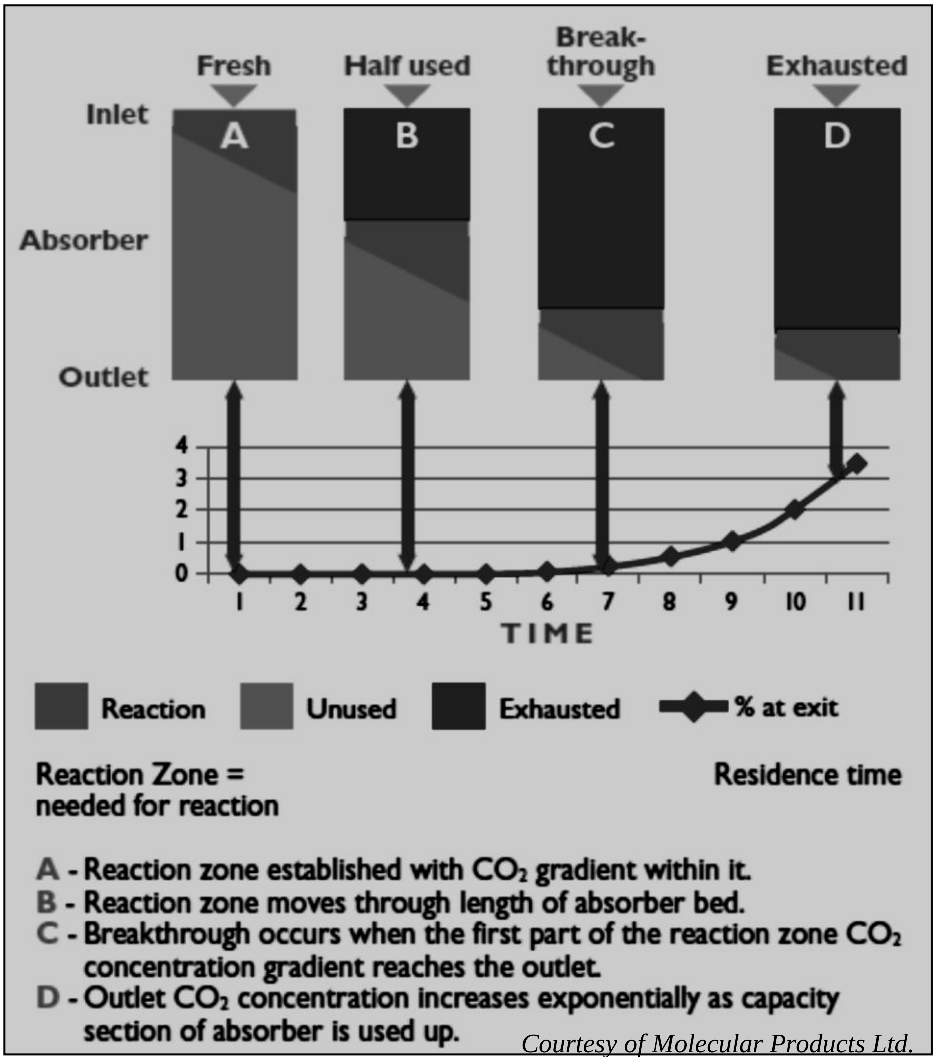


Figure 3: How an absorber works

Carbon Monoxide Sensors

There are three basic types of Carbon Monoxide sensors that monitor the concentration of CO on a certain period of time. These are: Biomimetic, Metal Oxide Semiconductor (MOS), and Electrochemical sensors (see Table 5).

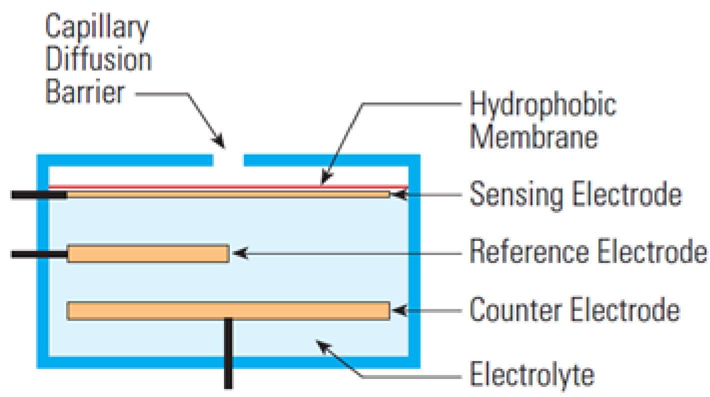
Table5: Comparison of carbon monoxide detection technologies

Sensor Technology	Advantage	Disadvantage
Biomimetic	- Low cost	- High false alarm rate
MOS	- Long Life Span	- High Current draw - Expensive - Non-selective, sensitive to chemicals and gases other than CO
Electrochemical	- Reliable, few field detects	- High sensitivity to ammonia-based cleaners

Courtesy of System Sensor

Electrochemical Sensors

According to Chapter 2 of Electrochemical Sensors by Intlsensor, the electrochemical sensor consists of the following key components: gas permeable membrane, electrode, electrolyte, and scrubber filter. The gas permeable membrane also known as hydrophic membrane, offers a mechanical protection to the sensor and the membrane performs the additional function of filtering out unwanted particulates. The selection of electrode is the most important factor to catalyze material which performs the half-cell reaction over a period of time. Then the electrolyte facilitates the cell reaction and carries the ionic charge across the electrodes, which are compatible with the sensor. The scrubber filter serves the front of the sensor which filters unwanted gases; the most frequently used filter medium is activated charcoal, which can filter most of the chemicals.



Courtesy of http://www.intlsensor.com/pdf/electrochemical.pdf

Figure 4: Typical Electrochemical Sensor Setup

Electrochemical sensors function by reacting with the gas of concern and producing an electrical signal proportional to the gas concentration. A typical electrochemical sensor comprises of a sensing electrode and a counter electrode separated by a thin layer of electrolyte as shown in Figure 4.

Chapter 3

CARBON MONOXIDE TO BREATHABLE AIR CONVERTER WITH ALARM SYSTEM FOR AUTOMOBILE

Abstract

Carbon monoxide (CO) gas is a compound produced by incomplete combustion of various carbon-based fuels and substances. The slow accumulation of this poisonous gas can cause headaches, nausea, vomiting, vertigo and confusion which are harmful for passengers' safety and environmental protection. The purpose of this study was to develop a carbon monoxide monitoring system for automobiles. The system includes a carbon monoxide detector which is capable of measuring concentration of the gas when it reaches the predetermined levels; the alarm system would notify the passenger/s and also the nearby people, at the same time it would prevent the hazardous gas to spread inside the vehicle. As a way for the system to save the passenger, the device will activate an exhaust fan connected inside the vehicle then it would be directed to a modified catalytic converter to release the trapped gas passing through the chemical reaction incorporating the soda lime for the soda lime air purification process.

Keywords: carbon monoxide monitoring system, catalytic converter, soda lime, alarm system, air purification process

Introduction

Carbonous oxide or commonly known as carbon monoxide (CO) is a colorless, odorless and tasteless gas that is fractionally lighter than air. It is a by-product of incomplete combustion of fossil fuels, such as those combustion fumes made by cars and trucks, lamps, stoves, gas ranges and heating systems. The carbon monoxide from these fumes can accumulate in places, as a result of poor installation, poor maintenance, failure or damage of an appliance in service, when the fuel is not burned properly, or when rooms are poorly ventilated and don’t have a good flow of fresh air for the CO to escape. These results can make the CO easily rise to potentially lethal and poisonous health risk. Since carbon monoxide is colorless, odorless, tasteless and initially non-irritating, it becomes very difficult for people to detect. Exposures to this toxic gas may lead to symptoms of mild acute poisoning including confusion, vertigo, headaches, dizziness and flu-like effects; larger exposures can lead to significant toxicity of the central nervous system and heart, and even death. Carbon monoxide can also have severe effects on the fetus of a pregnant woman. Prolonged exposure to low levels of carbon monoxide can lead to depression, confusion, and memory loss.

CO, one of the major causes of respiratory disease, is also addressed as the “Silent Killer”. It is the leading cause of accidental poisoning deaths in America. The US Center for Disease Control estimates that carbon monoxide poisoning claims nearly 500 lives, and causes more than 15,000 visits to hospital emergency departments annually.

Nowadays, carbon monoxide monitoring and alert systems are commercially available in the market. Most of these devices are installed at home/buildings and are also able to detect other dangerous gases in air while other systems are used in the mining industry. Although there are many variations of the carbon monoxide system, almost all of these are designed for buildings and home use only to detect the build up of poisonous gas in the air and notify the people inside.

This study aims to develop a system with proper application of system-connected carbon monoxide detectors that can monitor carbon monoxide concentration inside automobiles and convert this harmful gas into breathable air. The specific objectives of this study are to:

a) Integrate a catalytic converter with the use of soda lime.

b) Convert carbon monoxide into a breathable gas with implementation of ATMega168 microprocessor for the system's operation.

The study would significantly impart endeavor in assuring the health and safety of both the people and the environment. Since carbon monoxide poisoning and air pollution is a universal problem that the world is facing, this study would definitely contribute to the decrease of the cause of respiratory diseases and also the reduction of the emission of air pollutants in the environment. The study would also provide additional information by proposing a better way of detecting the amount of carbon monoxide entering the vehicle that possessed significant performance. Lastly, this research will be a helpful reference for other related studies in the future.

The study entitled "Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile" deals with the selected automobile such as cars and vans. The separation of the power supply unit of device from the vehicle's power supply which is tapped to the automobile's battery makes it more reliable in terms of performing the monitoring and releasing of the toxic gas, while the soda lime air purification process relies on the power of the vehicle since it requires the modified catalytic converter to function together with vehicle's power supply. The device is dependent on the amount of soda lime for the air purification process. The soda lime air purification process would take place if the quantity of carbon monoxide inside the automobile reaches the standard amount, however if the quantity is less than the standard, the system would remain idle.

Methodology

The prototype has followed appropriate steps from researching to leading to a conclusion. These include: [1] Gathered data from research materials such as IEEE journals and articles, books, and the internet which concern the thesis topic [2] Designed a block and schematic diagram for the whole system [3] Simulated the circuit by the appropriate software tool [4] Designed the PCB layout of the designed circuit [5] Built and soldered the components in the PCB [6] Tested the circuit [7] Created a program for the microcontroller [8] Uploaded the program in the microcontroller [9] Calibrated the sensor [10] Assembled the system [11] Preheated the sensor for some time [12] Tested the whole system for proper functionality(Gas Test) [13] Recalibrated when necessary [14] Resolved the system for errors [15] Stored and packed the final prototype into a clean environment, free of contamination [16] Recorded analysis and results, and had valuable conclusion.

Hardware Development

This section provides an overview of the steps that the researchers undertook in the hardware development of this design. Hardware development includes the flow of data through the components, block diagrams and schematic diagram of the design as well as components used in the design.

The hardware used include the ATMega168 microcontroller, an electrochemical CO sensor, buzzer, catalyst for the modified catalytic converter, PCB components, and an available car to be installed on by the system. Soda Lime is also included for the converting of gas.

The researchers constructed a block diagram that illustrates the flow of data in the design of the system which is shown in Figure 5.

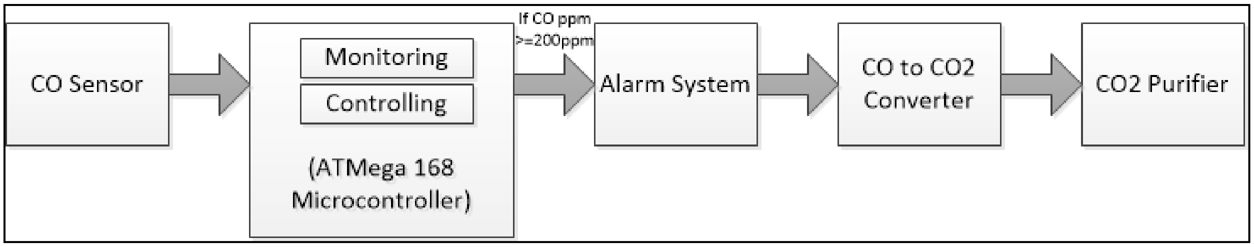


Figure 5: Block Diagram of the Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile

The block diagram shown in Figure 5 shows that the first step is done by the Carbon Monoxide sensor, which detects the amount of concentration of the said harmful gas and passes its analog value to the microcontroller unit. Then, from the microcontroller unit, based from the program burnt in it written in C language, it will pass signals to the CO to CO2 Converter and the Alarm System dependent on the conditions stated in Figure 6. The CO2 Purifier is connected to the CO to CO2 Converter meaning that the conversion process will have two major stages.

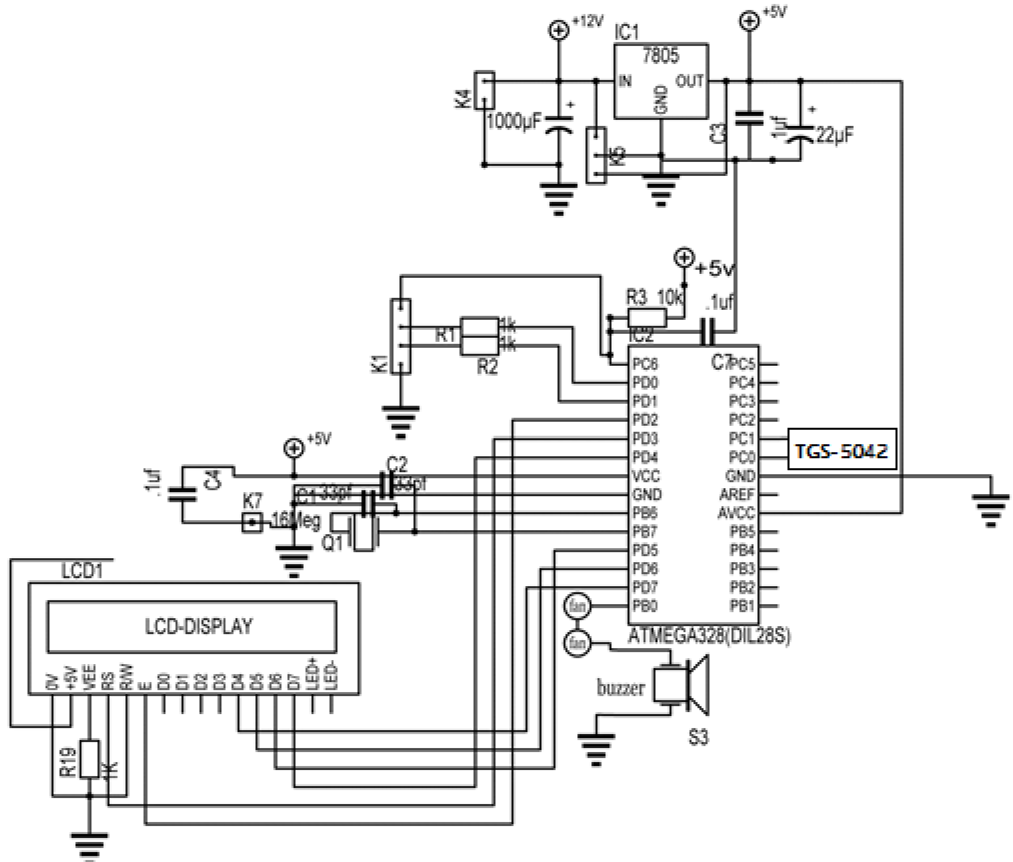


Figure 6: Carbon Monoxide Monitoring System Main Circuit Schematic Diagram

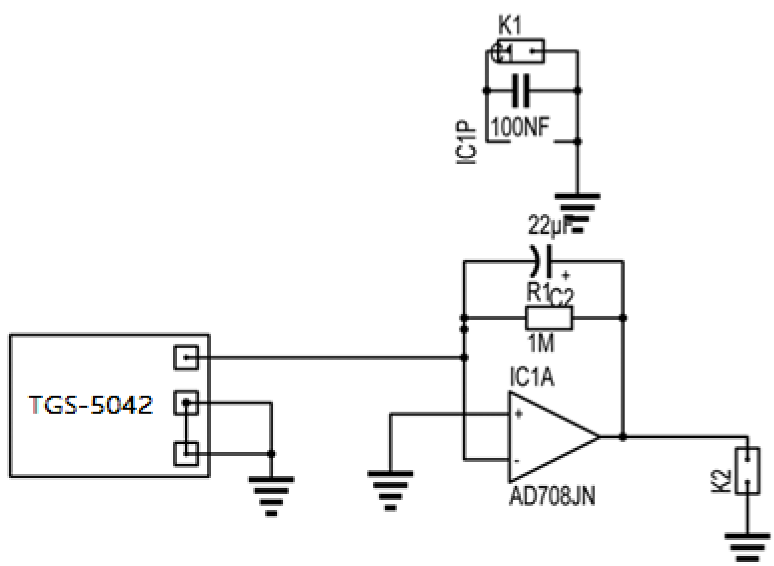


Figure 7: Carbon Monoxide with Electrochemical Sensor Circuit Schematic Diagram

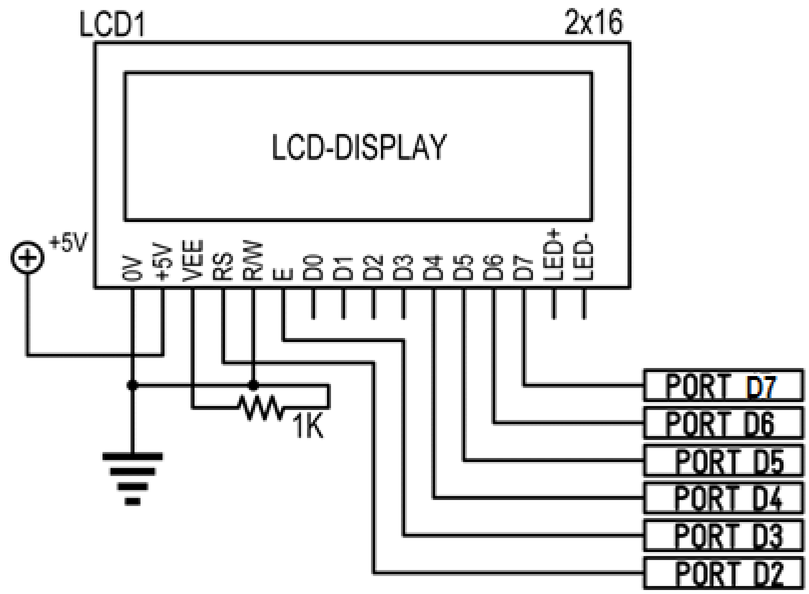


Figure 8: LCD Connection Circuit Schematic Diagram

Software Development

For programming purposes, Arduino software was used in interfacing with the hardware device applying C programming language which has predefined feature of the access to the serial port. C is preferred by the researchers because it has capabilities to access the device's low level functions. The system flow of the program is illustrated on page 23.

CO Concentration Equation

The formula for getting the CO concentration from the analog data coming from the CO sensor is the following:

$$CO(ppm) = 7.1808x10^{-2} \frac{ADC\_Output + 1}{Sensitivity\ (\frac{nA}{ppm})}$$

System Flow

The flowchart shown in Figure 9 states the steps on how the monitoring system operates. The first step is to preheat the sensor using the specified heating voltage for some time, and then reading its analog data to convert into concentration of the gas in terms of ppm unit. If the gas concentration reaches to 200 ppm and above, the Alarm System will raise and the CO conversion will take place, as shown in Figure 10. 200 ppm is selected because at this amount of CO, symptoms like headache could occur on a person in just 2-3 hours, and at levels higher than this, death is possible which is very dangerous.

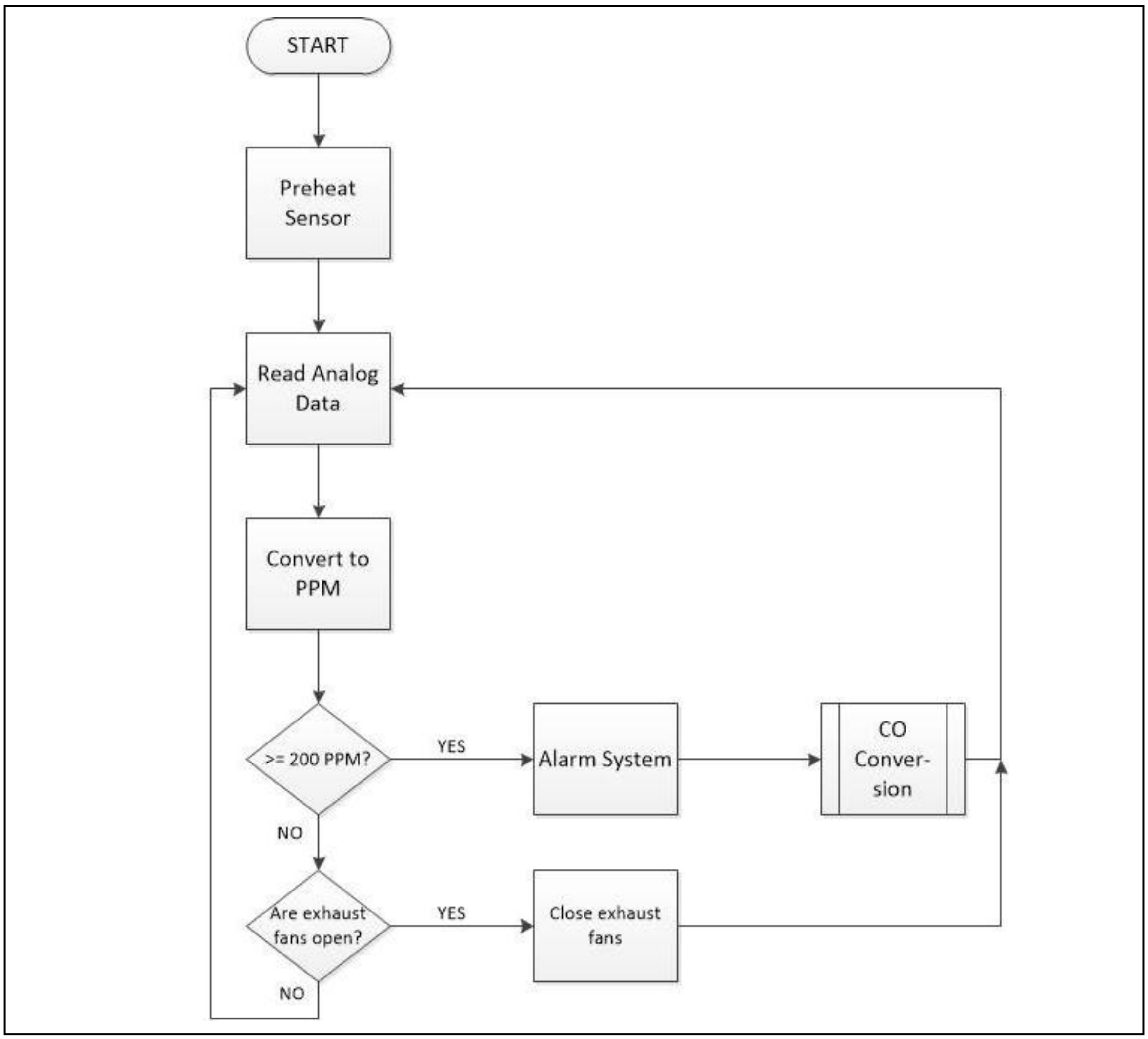


Figure 9: Flowchart of the Carbon Monoxide Monitoring System

From Figure 10 of page 24, after the Alarm System was triggered, there will be an alarm sound of the system, and it will stop if the passenger does so. On the conversion process, the first major stage is to convert CO to CO_2 by the concept of a catalytic converter. But in a catalytic converter, various harmful gases are being converted. For this proposal, it is only focused on the conversion of CO to CO_2, which has the formula, $2CO + O_2 \rightarrow 2CO_2$. The second major stage is the purification of CO_2 by means of the soda lime, as stated on the Soda Lime topic on page 12. An exhaust fan will be used for the absorption of the harmful gas into the converter.

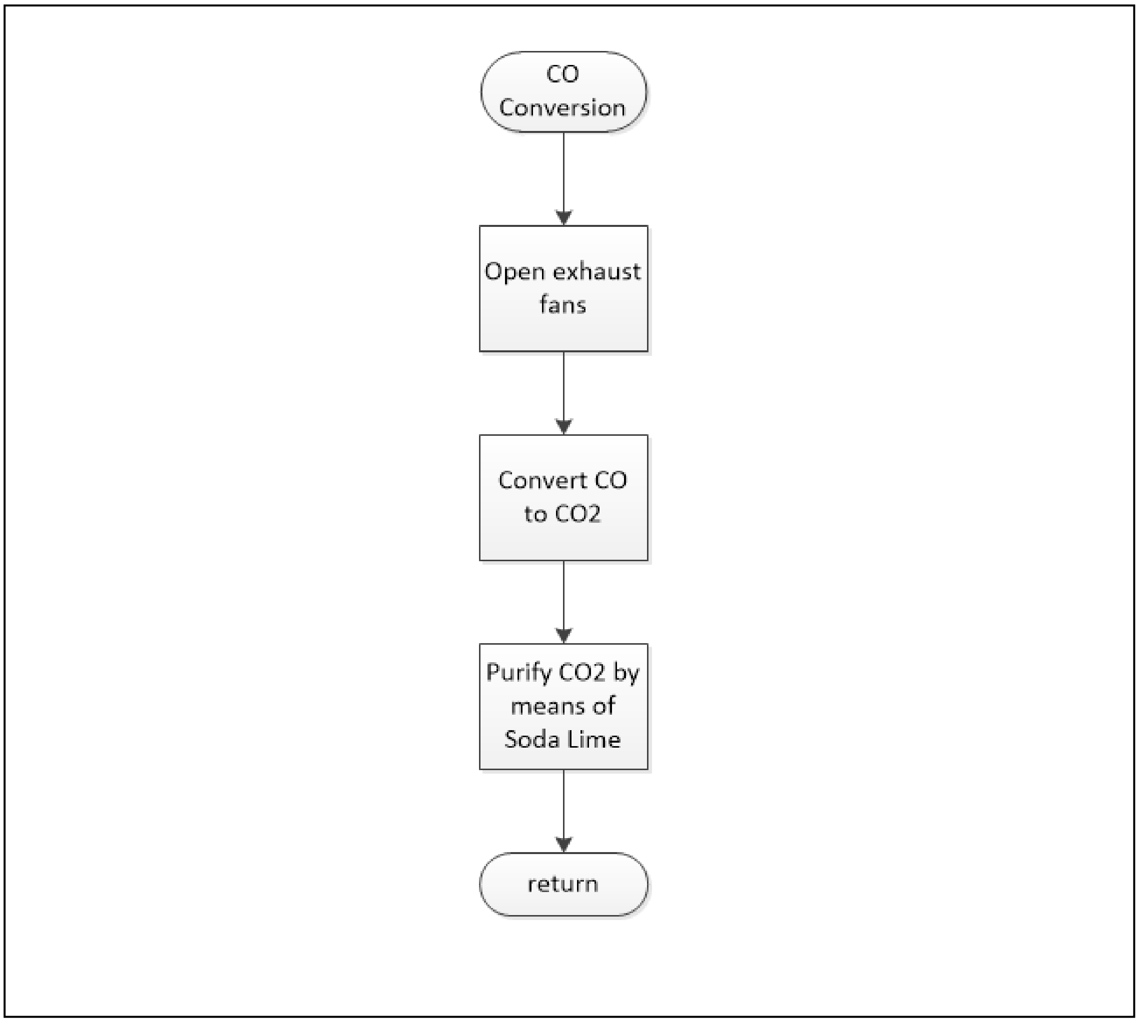


Figure 10: Flowchart of the Conversion Process

Tolerable level of CO

The choice of National Ambient Air Quality Objectives for carbon monoxide is based upon the clinical significance of health effects of concern, the number of people requiring protection, and the relationship between COHb levels, exposure, and ambient carbon monoxide levels.

COHb levels are a biomarker for the toxicity of ambient-level exposures to carbon monoxide and are used as an indicator of carbon monoxide exposure. Although more research is needed to evaluate the predictive capabilities of the CFK model in individuals exposed to low concentrations of carbon monoxide and its applicability to sensitive subpopulation (U.S. EPA, 1991), it is the best model available at present, and it will be used here to estimate appropriate National Ambient Air Quality Objectives for carbon monoxide. However, it must be remembered that models provide estimates based upon small numbers of representative measurements.

Table 6: Recommended National Ambient Air Quality Objectives, ppm (mg/m^3) [a]

Averaging Times	**Maximum Desirable Level**	**Maximum Acceptable Level**	**Maximum Tolerable Level**
1 hour	13 (15)	30 (35)	n/a
8 hours[b]	5 (b)	13 (15)	17.4 (20)
[a] 1 ppm = 1.146 mg CO/m^3 [b] rolling average			

Courtesy of http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/carbon-monoxyde-carbone/index-eng.php

As seen in Table 6, the maximum desirable levels are based on the carbon monoxide concentration that will result in a carboxyhemoglobin (COHb) blood level of less than 1%, or the upper end of the range of baseline COHb levels resulting from endogenous production. Based on the Coburn-Foster-Kane (CFK) equation, a 1-hour exposure of 13 ppm or an 8-hour exposure of 5 ppm would lead to less than 1 % COHB.

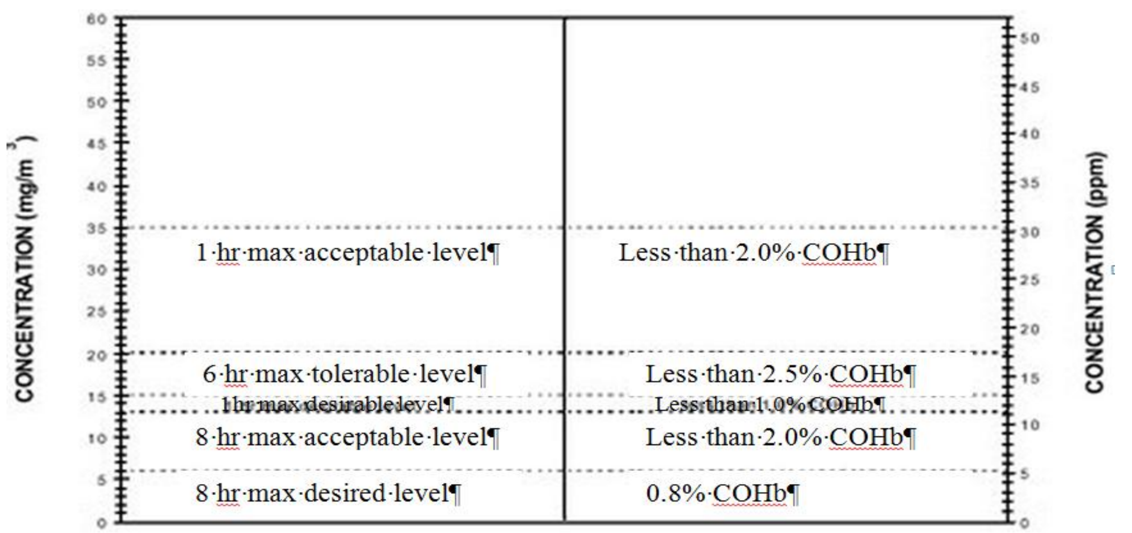
The recommended maximum acceptable levels for carbon monoxide are 30 ppm averaged over 1-hour and 13 ppm as an 8-hour rolling average. Results from five recent studies in 3 laboratories were consistent in finding adverse effects of COHb levels ranging from 2.9% to 6% (as measured by CO-Oximeter) or as low as 2% (as measured by gas chromatography) on exercise induced angina and on ECG (electrocardiogram) values. CO levels averaging 13 ppm over 8 hours or 30 ppm over 1 hour resulted in COHb levels at or below 2% for adults performing light work (ventilation rate of 18L/m).

Therefore, the maximum acceptable levels are based on the maintenance of COHb levels of less than 2%, thereby providing a small margin of safety. At levels above these concentrations, action would be required to decrease the probability or severity of effects in sensitive populations. Estimating COHb levels using pNEM indicates that less than 1% of the Toronto study area population will experience COHb levels greater than 2.0% if the ambient air quality is less than or equal to 13 ppm (15 mg/m^3) measured over 8 hours.

The recommended maximum tolerable level for an 8 hour exposure could be based on the lowest observed adverse effect level (LOAEL) of 2.9% COHb observed in the same experiments cited previously. This level would be approximately 21 ppm. However, the current tolerable level of 17 ppm is sufficiently close to this value to be retained as the objective. The recommended maximum tolerable level of 17 ppm averaged over 8 hours will result in a COHb level of about 2.5% as projected by the CFK model. This is still below the COHb levels believed to result in cardiorespiratory effects in the general population. Moreover, it is considered to be slightly more protective in accounting for non-standard conditions and people at the high end of the distribution curve for parameters used in the CFK equation. However, owing to a diminishing margin of safety within the tolerable range, action is recommended without delay when air quality exceeds the highest concentration of this range to protect the health of sensitive subgroups.

The averaging times chosen for the maximum desirable, acceptable, and tolerable ranges of carbon monoxide in ambient air are 1 and 8 hours. The latter averaging time approximates the length of time during which people may be exposed to carbon monoxide continuously in a particular location (e.g., work, sleep). More importantly, most individuals approach equilibrium levels of COHb in the blood after about 8-12 hours of exposure to (Anderson et al., 1973). Owing to the possibility of missing some events (high levels of carbon monoxide exposure) using a continuous averaging time, rolling averages are recommended for the calculation of the 8-hour average. The 1-hour averaging period is intended to be protective for effects that might occur following short exposures to high concentrations of carbon monoxide.

The 5 air quality objectives for carbon monoxide recommended in this report are illustrated in Figure 8, together with associated COHb levels as projected by the CFK model.



Courtesy of http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/carbon-monoxyde-carbone/index-eng.php

Figure 11: Recommended National Ambient Air Quality Objectives for Carbon Monoxide and Predicted COHb Levels

Devices and Equipment

- Exhaust fan for measuring the flow rate of the Carbon Monoxide to be converted.
- Catalytic converter is a device used to convert Carbon Monoxide to Carbon Dioxide.
- Soda lime is a compound that bonds with Carbon Dioxide.
- Power supply for the whole system.
- Air tight casing used to enclose the air being filtered.
- A tent used as a container of the carbon monoxide produced by any automobile.
- Hose used to channel the carbon monoxide coming from the automobile exhaust.
- Automobile used as the source of the carbon monoxide.

Test Environment

A tent was used to contain the carbon monoxide coming from the automobile as seen in Picture 1. A hose was then used to transfer the smoke from the automobile as seen in Picture 2. The air tight casing which contains the catalytic converter and soda lime was then placed inside the tent together with the sensors as seen in Picture 3. The tent will be filled with smoke which serves as the source of carbon monoxide. When the trigger values are reached, the exhaust fans will start the filtration process until the ideal level of carbon monoxide is brought back to normal. Refer to Appendix B.

Results and Discussion

Statistical Test

HYPOTHESIS 1

Null Hypothesis: The Alarm System is incorrect and leads to false alarm.

Alternative Hypothesis: The Alarm System has a correct function and does not lead to false alarm.

The first test involves the confirmation of the correct function of the alarm system with respect to the concentration to be responded. There were 20 trials, each of which was recorded in terms of concentration and if the alarm system would respond correctly. Univariate analysis using weighted arithmetic mean was used for the analysis and interpretation of data gathered since it involves only one variable. The expected answers vary depending on the CO concentration; for values less than 200 ppm, a NO answer is given a weight of 2 since it is the expected value while a YES answer is given a weight of 1. On the other hand, for values greater than or equal to 200 ppm, a YES answer is given a weight of 2 as it is the expected answer while a NO answer is given a weight of 1.

Table 7: Trails Involved on CO Concentration Pumped inside the Test Environment

Trial	CO Concentration (ppm)	Alarm activated?
1	9.63	NO
2	29.66	NO
3	40.79	NO
4	50.98	NO
5	62.18	NO
6	71.37	NO
7	91.77	NO
8	139.97	NO
9	155.73	NO
10	190.95	NO

11	205.22	YES
12	253.98	YES
13	383.75	YES
14	486.64	YES
15	551.53	YES
16	599.73	YES
17	673.88	YES
18	683.15	YES
19	695.2	YES
20	703.54	YES

Using the formula for weighted arithmetic mean for the twenty trials, the grand mean obtained was 2. This means that the Alarm System did not lead to false alarm and was able to activate correctly when predetermined levels are reached. Hence, the null hypothesis is rejected. (See Appendix G for the statistical computations)

HYPOTHESIS 2

Null Hypothesis: The system is not able to decrease the CO concentration

Alternative Hypothesis: The system is able to decrease the CO concentration

The second hypothesis claims that the system does not have the ability to decrease the input concentration of carbon monoxide (CO) to a much lower concentration. Such claim is proven true if there is no significant difference between the means of the two parameters tested. A total of 10 trials were performed, each of which was recorded every 30 seconds and in terms of concentration for initial and after process. The data were evaluated via Paired Two Sample for Means using t-testing, since the number of samples is less than 30 and this kind of testing is commonly used in before and after observations of data.

Table 8: Trails Involved on CO Concentration Before and After Conversion

Trial	CO Concentration (ppm) initial	CO Concentration (ppm) after
1	770.28	743.40
2	708.18	693.35
3	649.78	636.80
4	580.26	568.21
5	533.91	522.79
6	485.71	476.44
7	434.73	426.39
8	388.39	380.97
9	350.38	343.89
10	314.23	307.74

Table 9: Statistical Test on CO Concentration Before and After Conversion

Level of Significance	0.05
Level of Confidence	0.95
Critical Value	1.8331
t-value	6.0329
p-value	9.7E-5
Degree of Freedom	9
t<Critical Value	No

Using the hypothesis such that there is a decrease in CO concentration after being subjected to the system, a right-tail test was performed. With the degree of freedom value of 9 and significance level (alpha) of 0.05, a value of 1.8331 from the table of critical values of t was obtained. If the calculated t value is less than the critical t value, the null hypothesis is accepted and rejected if it is the other way around. Moreover, if the p-value is less than the significance level, then the null hypothesis is rejected and accepted otherwise. Since the calculated t value, which is 6.0329, is greater than the critical t value (1.8331), it can be said with 95% confidence that the system has the ability to decrease the concentration of CO. Thus, the null hypothesis is rejected. (See Appendix G for the statistical computations)

To be able to properly observe the behavior of the purification process, the researchers decided to increase the inputted amount of carbon monoxide to the tent until a 770.28 ppm is reached. It is done by continuously stepping on the gas of the vehicle used to produce smoke faster. In this way, the researchers were able to verify that the system is capable of purifying the air inside the test environment without a possible interruption. This additional procedure of increasing the CO concentration inside the tent is necessary for the testing of the systems effectiveness due to the fact that an input of 250 ppm to the tent is easily purified by the system thus the time for the researchers to observe, list down and gather the necessary information is not enough.

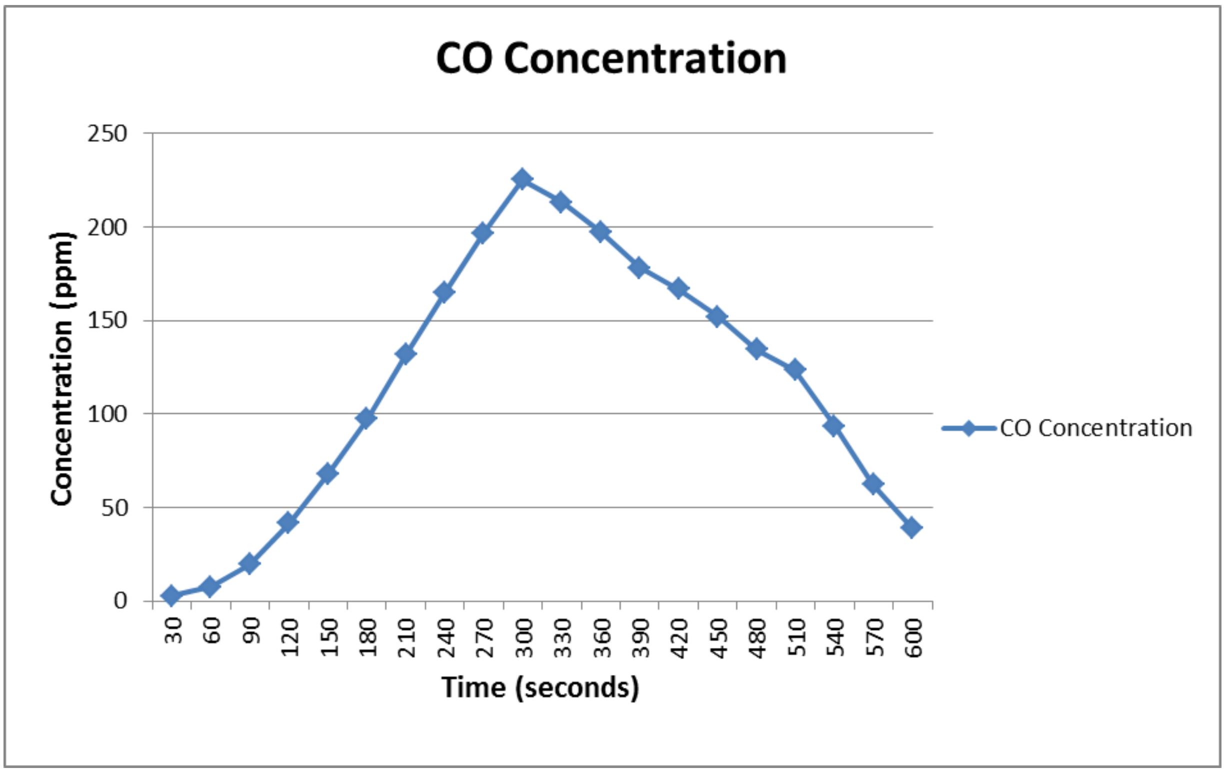


Figure 12: Graph of CO Concentration Initial and CO Concentration Final

Figure 12 shows the graphical representation of data for the rate of conversion table and the trials in Hypothesis 2. The CO concentrations were recorded for every 30 seconds; the first 300 of which was for the initial testing of the system wherein the CO concentration is starting to accumulate inside the test environment while the latter part (300-600 seconds) shows the trend at which the system was able to decrease the CO concentration to around 2-3.5% for every 30 seconds.

Conclusion

A system that can monitor carbon monoxide concentration and convert this harmful gas into breathable air through integration of catalytic converter and soda lime with implementation of ATMega168 microprocessor was designed and developed. Through univariate analysis using weighted arithmetic mean, it is proven that the system’s alarm function activates properly at designated levels and no false alarms have occurred. The conducted Paired Two Sample for Means t-testing gives the system 95% confidence of having the ability to decrease the amount of carbon monoxide concentration inside the automobile.

Chapter 4

CONCLUSION

This chapter provides the conclusions of the researcher after designing the Carbon Monoxide to Breathable Air Converter with Alarm System for Automobile device through testing and analysis. Accordingly, the device has room for suggestions to enhance by future researchers.

A system that can monitor carbon monoxide concentration and convert this harmful gas into breathable air through integration of catalytic converter and soda lime with implementation of ATMega168 microprocessor was designed and developed. Through univariate analysis using weighted arithmetic mean, it is proven that the system's alarm function activates properly at designated levels and no false alarms have occurred. The conducted Paired Two Sample for Means t-testing gives the system 95% confidence of having the ability to decrease the amount of carbon monoxide concentration inside the automobile.

Chapter 5

RECOMMENDATION

Here are some improvements that are made to enhance the design for the device in order to become more useful and to impose further innovation. The recommendations are as follows:

1. Convert carbon monoxide to oxygen with less energy required.
2. Increase the quantity and rapidity of conversion process.
3. Minimize size of device incorporating future technology such as nanotechnology.
4. Include storing of information gathered during the monitoring routine inside the test environment.
5. Incorporate new Smartphone technology such as Near-Field Communication (NFC) for faster transferring of data between the device and the smart phone.

REFERENCES

System Sensor © 2009, System-Connected Carbon Monoxide Detectors, 4

David G. Penney, *Carbon Monoxide Toxicity*, p.5, CRC Press, 2000 ISBN 0849320658. Lillo RS, Ruby A, Gummin DD, Porter WR, Caldwell JM (March 1996). "Chemical safety of U.S. Navy Fleet soda lime". *Undersea Hyperb Med* 23 (1): 43–53. PMID 8653065

Centers for Disease Control and Prevention, National Environmental Public Health Tracking Network, Carbon Monoxide Poisoning, accessed 2009-12-04

Gosink T (January 28, 1983). "What Do Carbon Monoxide Levels Mean?". *Alaska Science Forum*. Geophysical Institute, University of Alaska Fairbanks. Retrieved December 16, 2008

Green W. "An Introduction to Indoor Air Quality: Carbon Monoxide (CO)". United States Environmental Protection Agency. Retrieved 2008-12-16.

Maisel, William; Roger J. Lewis (2010). "Noninvasive Measurement of Carboxyhemoglobin: How Accurate is Accurate Enough?". *Annals of Emergency Medicine* (Boston, MA) 56 (4): 389–391.

"OSHA Fact Sheet: Carbon Monoxide". United States National Institute for Occupational Safety and Health.Retrieved 2009-09-14.

Wald, Nicholas (1981). "Carbon monoxide in breath in relation to smoking and carboxyhaemoglobin levels". *Thorax*: 366–369.

“Automobile Emissions: An Overview”. U.S. Environmental Protection Agency Office of Mobile Sources

“An Introduction to Sofnolime”, Molecular Products Ltd, Version 2, 28/05/09 MCL,JS

Calmorin, Laurentina P. and M. A. Calmorin (2007). *Research Methods and Thesis Writing*, 2nd edition, Book Store Inc., Sampaloc, Manila

APPENDIX A

Operation's Manual

Safety Precautions

⚠ WARNING

Statements provided below indicate pointers to prevent hazards from users when handling the unit:

- ✓ If one is using a power supply, never attempt to plug or unplug the power outlet when one's hand is wet. Push the plug all the way into the power outlet.
- ✓ The electrochemical sensor (TG5042) should be handled with care and should not be exposed to heat, radiation or anything that can lead to hardware failure.
- ✓ The carbon monoxide converter with catalytic converter should be handled with care and should not be exposed to heat, radiation or anything that can lead to hardware failure.

⚠ CAUTION

Caution Statements provided below indicate pointers for the unit safety handling to prevent hardware complications:

- ✓ The device is Electrostatic discharge (ESD) sensitive. Improper handling may result to damage. Do not touch any of the electronic components of the device placed inside the package.
- ✓ Do not place heavy objects on the device.
- ✓ Keep the device away from hot objects. Store the device in a cool, safe place to prevent damage.
- ✓ Never use any power supply greater than the required:12V

- ✓ Handle the unit with care. Do not drop the hardware.

Installation Procedure

1. Filled up the Carbon Monoxide Converter with Catalytic Converter with enough amount of soda lime.
2. Place the Carbon Monoxide Converter with Catalytic Converter inside the tent.
3. Connect the exhaust fan connection to the device.
4. Zipped the tent's zipper.
5. Connect the hose from the tent's allotted space to the automobile's exhaust.
6. Plug the device's cord to a 240 V AC Outlet.

User's Manual

1. Start the automobile's engine and pump enough smoke to fill up the tent.
2. Press the push button to start the calibration and measurement of the carbon monoxide.
3. The Carbon monoxide Converter with Catalytic Converter will start to cleanse the carbon monoxide inside the tent.
4. The alarm system will automatic triggered when the amount of carbon monoxide range from 200ppm and above.
5. As soon as the amount of carbon monoxide is reduced to below 200ppm the alarm will be deactivated.
6. To stop the monitoring, the user must unplug the cord.

Troubleshooting Guides and Procedures

1. If there is no output shown in the LCD display.

   1.1 Check if the push button is press.

1.2 Check if the cord is properly plugged to the outlet.

2. If the alarm system isn’t activated accordingly.

   2.1 Check if there is enough volume of carbon monoxide present inside the test environment.

   2.2 Check if the connection between the device and the Carbon monoxide Converter with Catalytic Converter is properly connection to each other.

3. If the alarm system doesn’t halt even if there is zero amount of carbon monoxide present inside the test environment.

   3.1 Check if the exhaust fan connection is appropriately connected.

   3.2 Check if the exhaust fan is working properly.

   3.3 Check if the conversion of the system is functioning accordingly.

   3.4 Check if the amount of soda lime is sufficient enough to proceed with the conversion process.

Error Definitions

1. Insufficient amount of Soda Lime.
2. Open air test environment.
3. Hardware malfunction.
4. Human error.

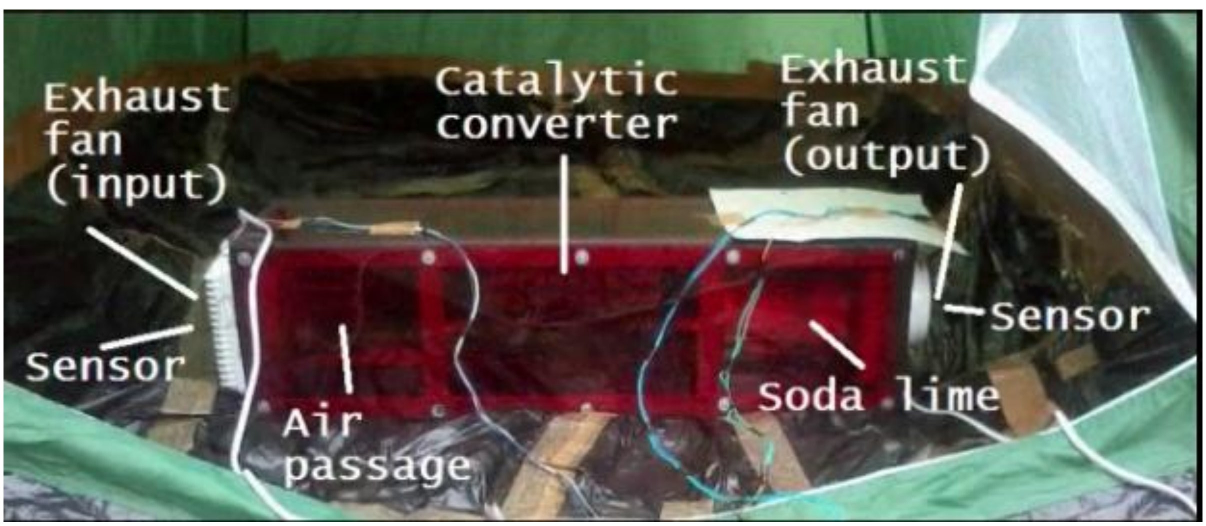
APPENDIX B

Pictures of Prototype

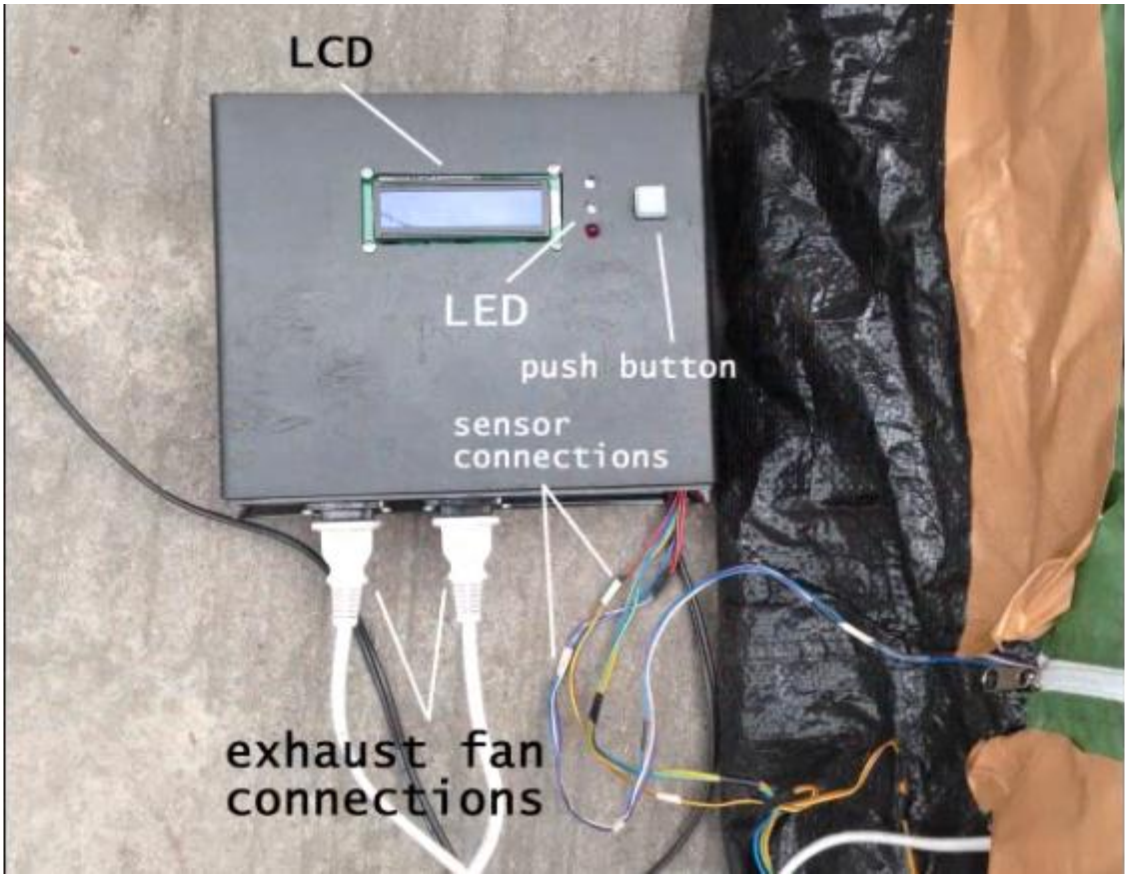
Picture 1: Tent as Test Environment

Picture 2: Source of Carbon Monoxide Connected to a Hose

Picture 3: Complete Setup of Carbon Monoxide Converter with Catalytic Converter



Picture 4: Carbon Monoxide Converter with Catalytic Converter



Picture 5: LCD Connected to Carbon Monoxide Converter with Catalytic Converter

APPENDIX C

Program Listing

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(7, 6, 5, 4, 3, 2);
int analogValue1 = 0;
int analogvalue2 = 0;
int proceed = 0;
int filter = 0;
float varVolt1 = 0;
float varvolt2 = 0;
float varFloat1 = 0;
float varFloat2 = 0;

int ledRed = 8;
int ledBlue = 10;
int buzzer = 11;

void setup(){
	lcd.begin(16, 2);
	pinMode(8, OUTPUT);
	lcd.setCursor(5,0);
	lcd.print("CARBON");
	lcd.setCursor(4,1);
	lcd.print("MONOXIDE");
	delay(3000);
	lcd.clear();
```

```
        lcd.setCursor(2,0);
        lcd.print("CALIBRATING!");
        lcd.setCursor(1,1);
        lcd.print("PLEASE WAIT...");
        delay(180000);
        lcd.clear();
}

void loop(){

        analogValue1 = analogRead(A0);
        analogValue2 = analogRead(A1);
        delay(500);

        varVolt1 = ((analogValue1*4.88)/1000);
        varFloat1 = ((varVolt1)/0.00526466);

        varVolt2 = ((analogValue2*4.88)/1000);
        varFloat2 = ((varVolt2)/0.00526466);

        lcd.clear();
        lcd.setCursor(0,0);

        if(varFloat1 < 200 && varFloat2 < 200)
        {
                proceed = 1;
                digitalWrite(ledRed, LOW);
```

```
        digitalWrite(ledBlue, HIGH);
        digitalWrite(buzzer, LOW);
        lcd.print("SAFE CONDITION");
    }
    else if(proceed == 1)
    {
        if(varFloat1 >= 200)
        {
            digitalWrite(ledRed, HIGH);
            digitalWrite(ledBlue, LOW);
            digitalWrite(buzzer,HIGH);
            lcd.print("DANGER!>CLEANING");
        }
    }

    lcd.setCursor(0,1);
    lcd.print(varFloat1,2);
    lcd.setCursor(9,1);
    lcd.print(varFloat2,2);

}
```

APPENDIX D

Data Sheets

FIGARO PRODUCT INFORMATION

TGS 5042 - for the detection of Carbon Monoxide

Features:

* Battery operable
* High repeatability/selectivity to carbon monoxide (CO)
* Linear relationship between CO gas concentration and sensor output
* Low sensitivity to ethanol
* Reduced influence by various interference gases
* Long life

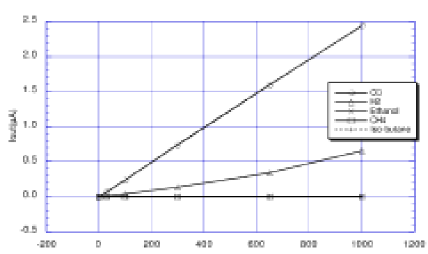
Applications:

* Residential and commercial CO detectors
* CO monitors for industrial applications
* Ventilation control for indoor parking garages

Figaro's **TGS5042** is a new electrochemical CO sensor possessing improved characteristics. By using very low concentration alkaline electrolyte, integration of an extremely small amount of noble metal catalyst into the catalyst layer, and application of a separator, TGS5042 has the advantage of being more environmentally friendly than traditional electrochemical sensors. Using a dry battery structure, TGS5042 poses no risk of electrolyte leakage and offers characteristics superior to those of traditional electrochemical CO sensors.

The figure below represents typical sensitivity characteristics, all data having been gathered at standard test conditions (see reverse side of this sheet). The Y-axis shows theoutput current of the sensor (Iout/μA) in each gas. Output current is linear to CO concentration, with a deviation of less than ±5% in the range of 0~500ppm.

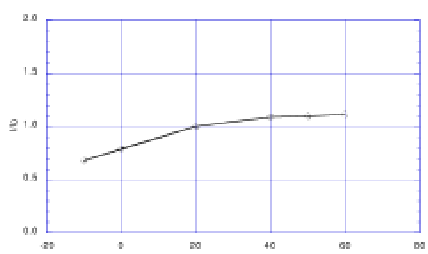
Sensitivity Characteristics:



The figure below represents typical temperature dependency characteristics. The Y-axis shows the sensor output ratio (I/Io) as defined below. The linear relationship between I/Io and CO concentration is constant regardless of the CO concentration range.

I = Sensor output current in 400ppm of CO at various temperatures
Io = Sensor output current in 400ppm at 20°C/50%RH

Temperature Dependency:



IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET GASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

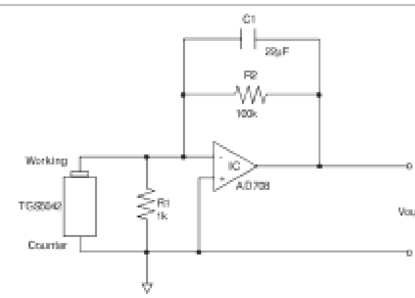
Basic Measuring Circuit:

The diagram at the right shows the basic measuring circuit of TGS5042. The sensor generates a minute electric current which is converted into sensor output voltage (Vout) by an op-amp/resistor (R2) combination. An additional resistor (R1) is required to prevent polarization of the sensor when circuit voltage is off.

Figaro recommends the following electrical parts:

R1 : 1kΩ
R2 : 100kΩ
C1 : 22µF
IC : AD708

NOTE: When voltage is applied to the sensor output terminal, the sensor may be damaged. Voltage applied to the sensor should be strictly limited to less than ±10mV.



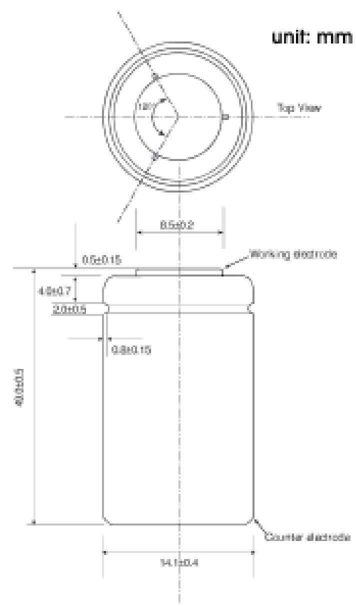
Basic measuring circuit of TGS5042

Specifications:

Item	Tentative Specification
Model number	TGS 5042
Target gases	Carbon monoxide
Typical detection range	0 ~ 1000 ppm
Output current in CO	1.00~3.75nA/ppm
Baseline offset	<±15ppm equivalent
Operating temperature	-10 ~ +60˚C
Operating humidity	5 ~ 99%RH (no condensation)
Response time (T90)	within 60 seconds
Expected accuracy (*)	±20% at 0-100ppm of CO ±15% at 100-500ppm of CO (at 20±5˚C/50±20%RH)
Storage conditions	-40 ~ +70˚C
Weight	approx. 12g
Standard test conditions	20±2˚C, 40±10%RH

(*) *assumes calibration points of 0 and 500ppm of CO, exposure time of 4 minutes, one day of aging in detector.*

Structure and Dimensions:

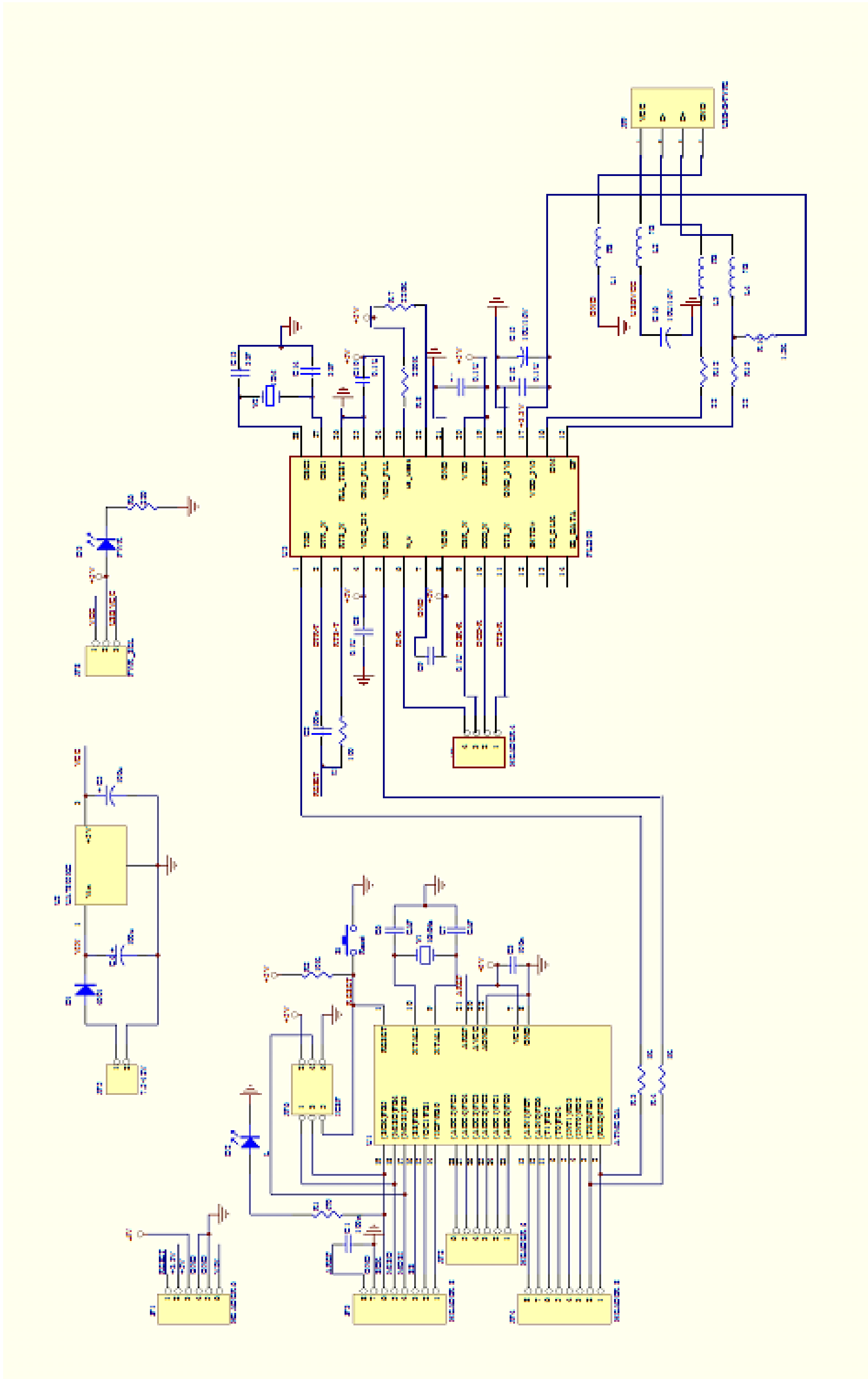


FIGARO ENGINEERING INC.
1-5-11 Senba-nishi
Mino, Osaka 562-8505 JAPAN
Phone: (81)-72-728-2561
Fax: (81)-72-728-0467
email: figaro@figaro.co.jp

REV: 04/05

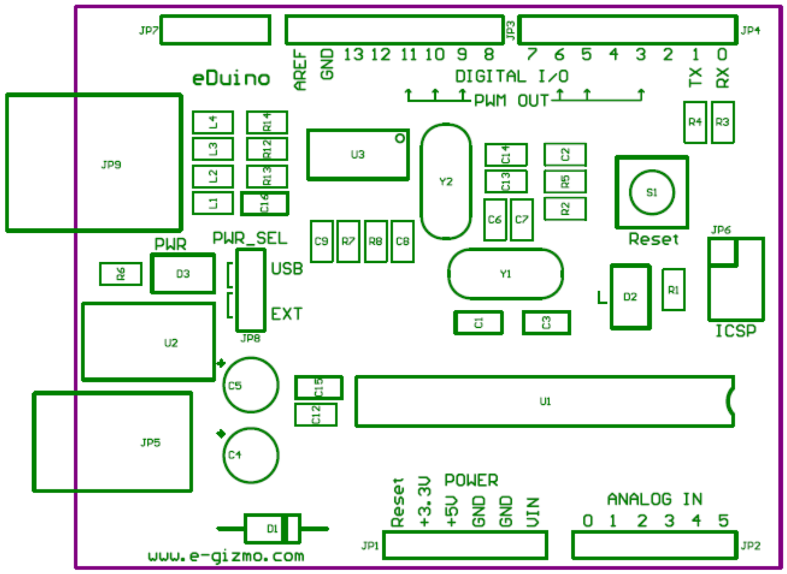
APPENDIX E

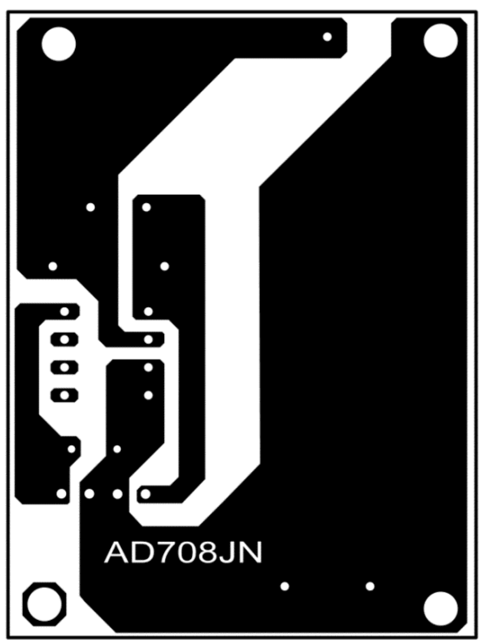
Schematic Diagram of ATMega168 Arduino

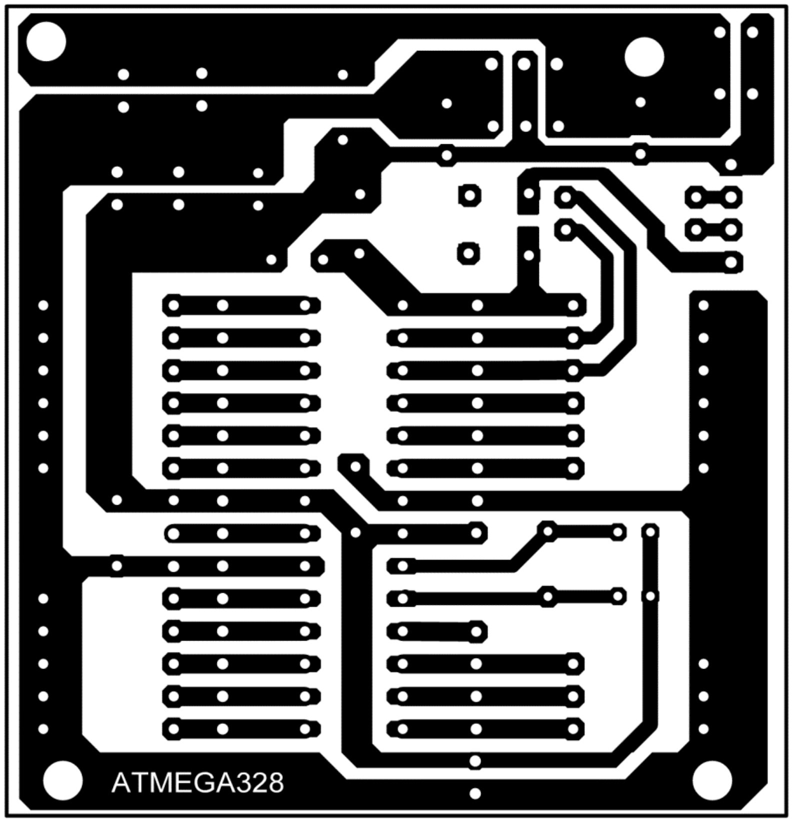


APPENDIX F

PCB Layouts






ATMEGA328

APPENDIX G

Statistical Computations

HYPOTHESIS 1

Trial	CO Concentration (ppm)	Alarm activated?
1	9.63	NO
2	29.66	NO
3	40.79	NO
4	50.98	NO
5	62.18	NO
6	71.37	NO
7	91.77	NO
8	139.97	NO
9	155.73	NO
10	190.95	NO
11	205.22	YES
12	253.98	YES
13	383.75	YES
14	486.64	YES
15	551.53	YES
16	599.73	YES
17	673.88	YES
18	683.15	YES
19	695.2	YES
20	703.54	YES

At CO concentration less than 200 ppm

Scale:

2 – NO

1 – YES

At CO concentration greater than or equal to 200 ppm

Scale:

2 – YES

1 – NO

	f	x	fx
	20	2	40
	0	1	0
Total	20		40

$\overline{X} = \frac{\sum fx}{\sum f}$ (formula for weighted arithmetic mean)

where:

$\overline{X}$ = weighted arithmetic mean

$\sum fx$ = sum of all the products of f and x

$\sum f$ = sum of all the frequency/subjects

$$\overline{X} = \frac{20(2) + 0(1)}{20}$$

$\overline{X} = 2$ (NO @ CO concentration < 200ppm & YES @ CO concentration >= 200 ppm)

HYPOTHESIS 2

Trial	CO Concentration (ppm) initial	CO Concentration (ppm) after
1	770.28	743.40
2	708.18	693.35
3	649.78	636.80
4	580.26	568.21
5	533.91	522.79
6	485.71	476.44
7	434.73	426.39
8	388.39	380.97
9	350.38	343.89
10	314.23	307.74

t-Test: Paired Two Sample for Means

		Variable 1	*Variable 2*
$\overline{X}$	Mean	521.585	509.998
SD^2	Variance	23952.72	22332.26
N	Observations	10	10
	Pearson Correlation	0.999816	
	Hypothesized Mean Difference	0	
	df	9	
t-value (t)	t Stat	6.03286	
p-value	P(T<=t) one-tail	9.73E-05	
critical value	t Critical one-tail	1.833113	
	P(T<=t) two-tail	0.000195	
	t Critical two-tail	2.262157	

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{SD_1^2}{N_1} + \frac{SD_2^2}{N_2}}} = \frac{521.585 - 509.998}{\sqrt{\frac{23952.72}{10} + \frac{22332.26}{10}}}$$

$$t = 6.0328$$

APPENDIX H

List of Materials

Quantity	Item	Price per unit	Total amount
1	Transformer 1amp	₱260	₱260
2	Exhaust Fan	₱300	₱900
1	AC Cord	₱50	₱50
1	Relay	₱90	₱90
1	Terminal Block	₱18	₱18
1	LCD	₱480	₱480
2	Outlet	₱20	₱40
4	Capacitor (47µF)	₱10	₱40
4	Capacitor (470 µF)	₱10	₱40
2	Capacitor (22 µF)	₱5	₱10
1	Resistor (100Ω)	₱1	₱1
2	Resistor (1kΩ)	₱1	₱2
1	Resistor (22kΩ)	₱1	₱1
1	Resistor (100kΩ)	₱1	₱1
2	Resistor (1mΩ)	₱1	₱2
1	LED	₱3	₱3
9	IN4001 Rectifier Diode	₱3.50	₱31.50
2	AD708JN IC	₱10	₱20
1	9014 Transistor	₱5	₱5
4	L7912 Transistor	₱50	₱200
1	HC 841-01 Casing	₱180	₱180
3	8 pins IC socket	₱25	₱75
4	3 pins Female & Male Connector	₱12	₱48
2	Electrochemical Sensors (TGS5042)	₱1500	₱3000
1	Soda Lime (1 kg)	₱1000	₱1000
1	Catalytic Converter	₱5000	₱5000
1	ATMEGA168 Arduino	₱950	₱950
2	Set of wires	₱20	₱40
		Total	**₱12487.50**