Investigation of the Interior Air Quality of Taxicabs Using LPG

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Abstract: This study investigated the interior air quality of the air-conditioned taxicabs using liquefied petroleum gas in Metro Manila. The air contaminants assessed include chemical contaminants (carbon dioxide, butane/propane, carbon monoxide, sulfur dioxide, and nitrogen dioxide), biological contaminants and particulate matter (PM10). An interview of the drivers was conducted to determine the common discomforts they experience while driving the taxicabs. The study recommends some interventions to maintain good interior air quality of the taxicab. The results indicate high concentrations of carbon dioxide with values exceeding the 1000ppm allowable limit set by the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE). Aside from carbon dioxide, the harmful chemicals butane/propane and carbon monoxide were found inside the taxicabs. Generally, the concentration of the biological contaminants inside the taxicabs was within the acceptable level of 1000 cfu/m^3 set by the American Conference of Governmental Industrial Hygienist (ACGIH). Eight out of twenty taxicabs had PM10 concentrations above the acceptable level of 150μg/m^3 set by the National Ambient Air Quality Standards for Particle Pollution (NAAQS). Based on the results of the survey, skin allergy, headaches, and dry throat were the most common illnesses/discomforts cited by the drivers.

***Key words*:** interior air quality, chemical and biological contaminants, particulate matter

1. INTRODUCTION

Air pollution is the accumulation in the atmosphere of substances that, in sufficient concentrations, endanger human health or produce other effects on living matter and other materials. Air pollution increases premature mortality caused by lung cancer and other respiratory and cardiovascular diseases. Subjects with respiratory conditions experience symptoms due to exposure to air pollution leading to an increased medication, sick leaves, and low performance in learning and working. Air pollution is often identified with major stationary sources (such as power plants and factories), but the greatest source of emissions is mobile sources, mainly automobiles.

In the study conducted by the National Occupational Safety and Health (NIOSH) in 1989, people spend more than 90% of their time indoors, with traveling inside transport microenvironments (cars, buses, trains, etc.) accounting for seven percent. Numerous scientific studies conducted in the past decades reveal that in-car air pollution levels are higher than that of the nearby ambient air or even the air at the side of the road. Reports show that the air inside of cars contains more carbon monoxide, benzene, toluene, fine particulate matter and carbon dioxide than the ambient air.

These higher in-vehicle concentrations of pollutants intensify the over-all exposure of drivers and passengers to a toxic mix of very dangerous chemicals including benzene, particulate matter, carbon monoxide, etc. Since it receives little attention from the public, and from private and government institutions, it may pose one of the greatest modern threats to human health.

2. REVIEW OF RELATED LITERATURE

Several studies on indoor air quality have been undertaken by the mechanical engineering departments of the Mapua Institute of Technology and the De La Salle University – Manila. These include indoor air quality investigations inside classrooms, libraries, shopping malls, laboratories and transport microenvironments. Four mechanical engineering undergraduate theses on interior air quality on surface transportation from both schools are cited in this study.

Bosshard, et al. (2003) investigated the interior air quality of air-conditioned buses plying the route Moonwalk (Las Piñas) to Lawton (Manila) and vice-versa. The research considered chemical contaminants such as carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), benzene (C_6H_6), and toluene (C_7H_8), as well as particulate matter (PM2.5). The results revealed that NO_2, SO2, and C_6H_6 concentrations were beyond those limits given by the Canadian Indoor Air Quality Standard. On the other hand, CO and CO_2 concentrations were at acceptable levels. No trace of C_7H_8 was detected in all the sampling performed. The concentration level of particulate matter was also within the acceptable level based again on the Canadian Indoor Air Quality Standard.

Pua, et al. (2006) assessed the interior air quality of air-conditioned ship cabins of motor vessels traversing the route Manila-Cebu and vice-versa. Except for carbon dioxide (CO_2), there was no trace of other chemical contaminants such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), benzene (C_6H_6), and toluene (C_7H_8) in the ship cabins. Both the concentrations of carbon dioxide and particulate matter (PM2.5) were within the acceptable limits set by the Canadian Indoor Air Quality Standard. On the other hand, biological contaminant concentration exceeded the 1000 cfu/m^3 guideline provided by the American Conference of Governmental and Industrial Hygienists (ACGIH).

Correa, et al. (2008) investigated the interior air quality of air-conditioned trains of the Light Rail Transit (LRT) in Metro-Manila. The air contaminants assessed included chemical contaminants (carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxide and volatile organic compounds such as toluene and benzene), biological contaminants, and particulate matter. A survey was conducted to determine the sicknesses/illnesses contracted by the passengers which may be due to poor interior air quality. The study recommended some interventions to maintain good interior air quality of the trains. Results indicated a high concentration of carbon dioxide during peak time but it was still within the acceptable limit as set by the Occupational Safety and Health Center of the Department of Labor and Employment. There was no trace of the other chemical contaminants found in the trains. Generally, the concentration of biological contaminant was within the acceptable level of 1000 cfu/m3 set by the American Conference of Governmental Industrial Hygienist.

Austria, et al. (2004) assessed the interior air quality of air-conditioned buses, and recommended interventions on how to improve the air quality. The research considered carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), volatile organic compounds, as well as biological contaminants. The results of the sampling revealed that the concentration levels of all chemical contaminants were below the limit provided by the Canadian Indoor Air Quality Standards and the Occupational Safety and Health Center of the Department of Labor and Employment. Biological contaminant concentration exceeded the 1000 cfu/m^3 guideline provided by the American Conference of Governmental and Industrial Hygienists (ACGIH). However, because of the installation of an intervention in the bus, ultraviolet C (UVC) light, the concentration of biological contaminants decreased.

3. OBJECTIVES

The study investigated the interior air quality of twenty LPG-powered taxicabs plying in Metro Manila. Specifically, the study has the following objectives:

- Determine the concentration level of chemical contaminants which include carbon dioxide (CO_2), carbon dioxide (CO), butane (C_4H_{10}), propane (C_3H_8), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2).
- Determine the concentration level of biological contaminants and particulate matter (PM10)
- Conduct a survey among taxi drivers to determine the usual discomforts/illnesses they experience

4. METHODOLOGY

Air samplings for this preliminary interior air quality study were done during the month of March 2009 in twenty randomly selected LPG-powered taxicabs. Active and passive sampling methods were used in the conduct of the sampling. Colorimetric gas detection tubes attached to a handheld vacuum pump were used to determine the concentration level of carbon monoxide, butane/propane, sulfur dioxide and nitrogen dioxide. In measuring the concentration of carbon dioxide, a direct reading device was used. Gravimetric method using an IOM sampler was employed in determining the concentration of particulate matter. Tryptic soy agar, a non-selective nutrient medium, was used to measure the concentration level of biological contaminants. For every taxicab, measurements were taken for thirty minutes. An interview among the taxi drivers was also done to determine the common discomforts/illnesses they experience while driving the taxicabs.

5. DISCUSSION OF RESULTS

The data presented in the graphs that follow were obtained by employing the various methodologies chosen for air sampling.

Except for nitrogen dioxide and sulfur dioxide, all the other chemical contaminants were found inside the taxis. Although some studies reveal the presence of sulfur oxides and nitrogen oxides inside vehicles, the concentration of the said chemicals inside the taxicabs tested may be very low for it to be detected by the use of colorimetric method.

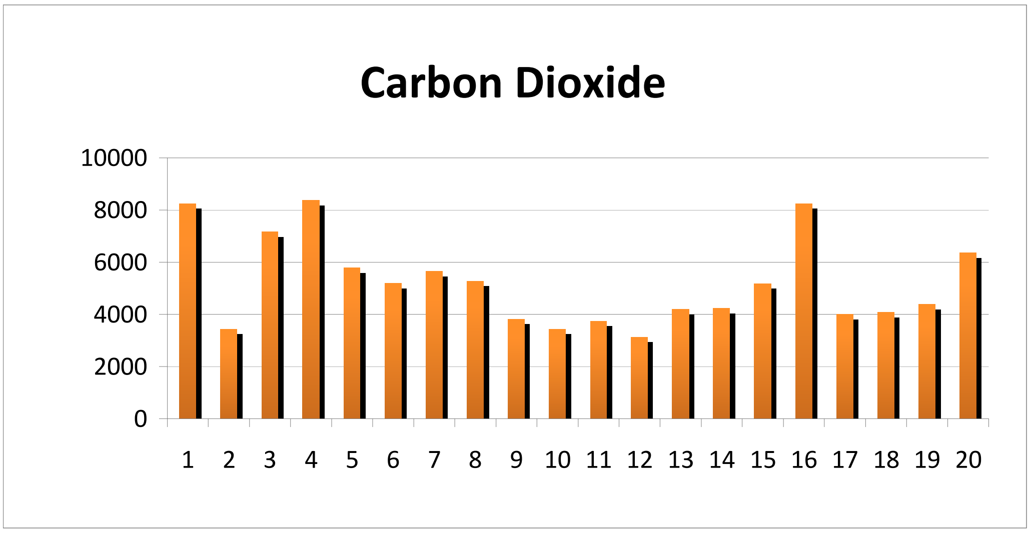

Figure 1. Concentration of Carbon Dioxide

Figure 1 shows the overall average readings of the level of concentration of carbon dioxide (CO_2). Carbon dioxide is a colorless, odorless, and non-flammable gas. Common sources of this gas include human and animal respiration, as well as combustion products of substances containing carbon. High levels coupled with long-term exposure result in complaints of odors, "stuffy air", sleepiness, fatigue and headaches.

The high concentration of carbon dioxide in the taxicabs may be attributed to the poor ventilation provided by the car. This may be due to poor maintenance of the air-conditioning system of the vehicle. Low carbon dioxide concentrations were recorded in taxi 12 (3132 ppm), taxi 10 (3436 ppm), taxi 2 (3439 ppm), taxi 11 (3742 ppm) and taxi 9 (3818 ppm). Most of the peak concentrations of CO_2 were observed in taxi 1 (8242 ppm), taxi 4 (8367 ppm), and taxi 16 (8250 ppm). High concentrations of carbon dioxide were observed especially during congested traffic conditions. The large number of surrounding vehicles as well as the ambient air conditions might have affected the level of CO_2 inside the taxi.

In a similar interior air quality study done by Baldove, et al. (2009) in taxicabs running on gasoline, high carbon dioxide concentrations were also observed. Concentration levels ranged from 2078 ppm to 9455 ppm. The high concentrations were likewise observed during traveling on congested roads and through busy intersections.

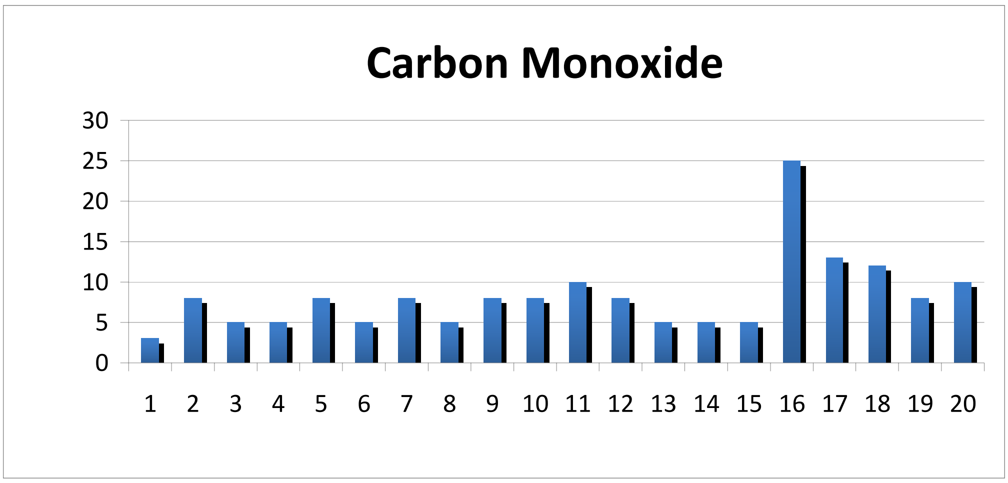

Figure 2. Concentration of Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, poisonous gas that is a by-product of incomplete combustion. Acute carbon dioxide poisoning occurs when inhaled CO combine with hemoglobin in the blood, inhibiting the blood's ability to carry and exchange oxygen to the brain, heart, and other bodily organs and tissues. Moderate exposure may produce flu-like symptoms – headaches, dizziness, and weakness – in healthy individuals.

From Figure 2, it can be observed that various carbon monoxide levels were detected in all the taxicabs. The highest carbon monoxide concentration was found in taxi 16, with 25 ppm. However, this value is still within the acceptable limit of 50 ppm as given by the Occupational Safety and Health Administration. In a 1997 study by researchers at the University of Nottingham, it was found out that drivers in that city in England were exposed to average CO levels between 3 and 22 ppm. High concentrations typically resulted when the test car followed behind a particularly dirty lead vehicle when the test car passed through extremely busy intersections. In a 1992 study done in Riyadh, Saudi Arabia, average interior CO concentrations ranged from 10 to 25 ppm during non-peak traffic times, and 30 to 40 ppm during rush hour periods.

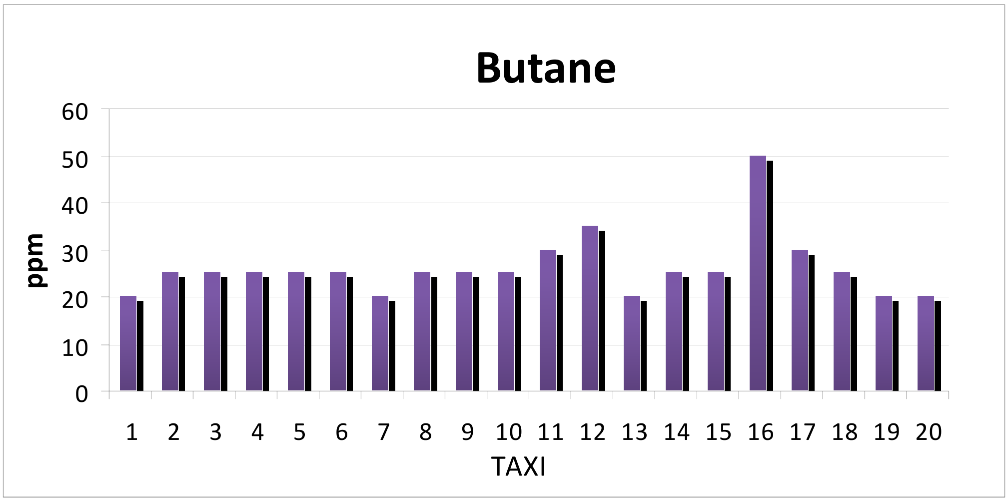

Figure 3. Concentration of Butane

Figure 3 shows that the butane concentration inside the taxis varied between 20ppm and 30ppm, except for taxi 12 and taxi 16 whose concentrations were 35ppm and 50ppm, respectively. Butane is a simple asphyxiant with explosive and flammable potential. Inhalation may cause headache, dizziness, loss of consciousness, drowsiness and coma. In the said taxicabs, the researchers experienced dizziness and headache due to an unfamiliar smell inside the taxicab.

Similarly, high concentrations of carbon monoxide and butane/propane were observed during congested traffic conditions. Butane/propane may have come from the taxi itself, and carbon monoxide from outside air. The results further support the findings of several studies which suggest that a large portion of in-vehicle pollution is caused by emissions from outside vehicles during congested traffic conditions.

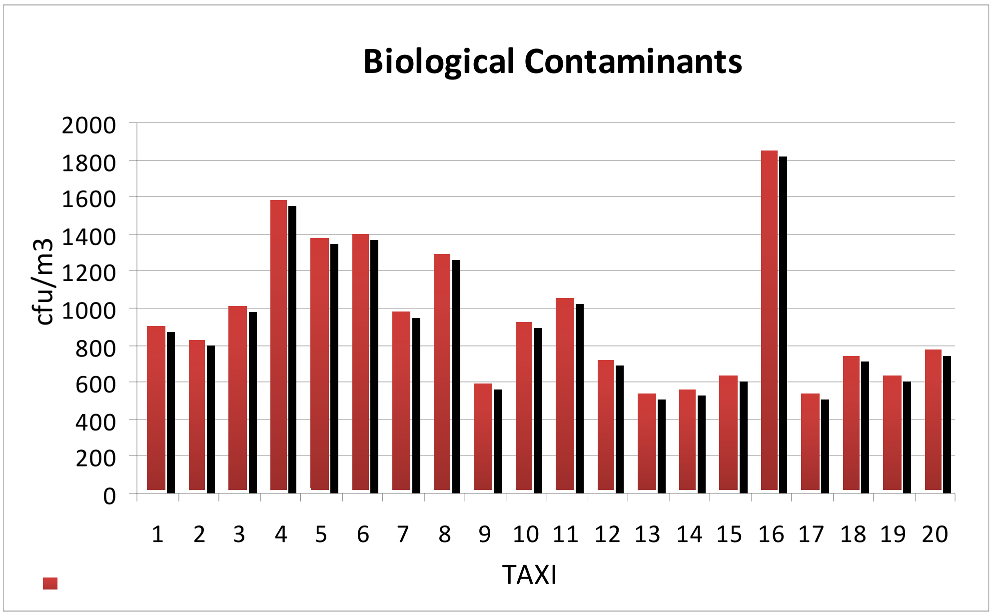

Figure 4. Concentration of Biological Contaminants

The biological contaminants were determined using the soy agar medium. Biological contaminants are minute particles of living matter (bacteria, fungi, molds) produced from a variety of sources. These contaminants cause varying levels of irritation in certain individuals, including allergic reactions, headaches, eye irritation, sneezing, fatigue, nausea, difficult breathing and more.

The exposure of agar plates in the taxi was done manually by placing the plates in the middle of the taxi near the hand break. The colony forming units per plate were determined by counting them in the laboratory using a colony counter. In Figure 4, it can be seen that the highest concentration of biological contaminants was found in taxi 16 (Mapua to Sta. Cruz) with 1834 cfu/m^3. Taxi 13 and taxi 17 recorded the lowest concentration of biological contaminants, each with 524 cfu/m^3.

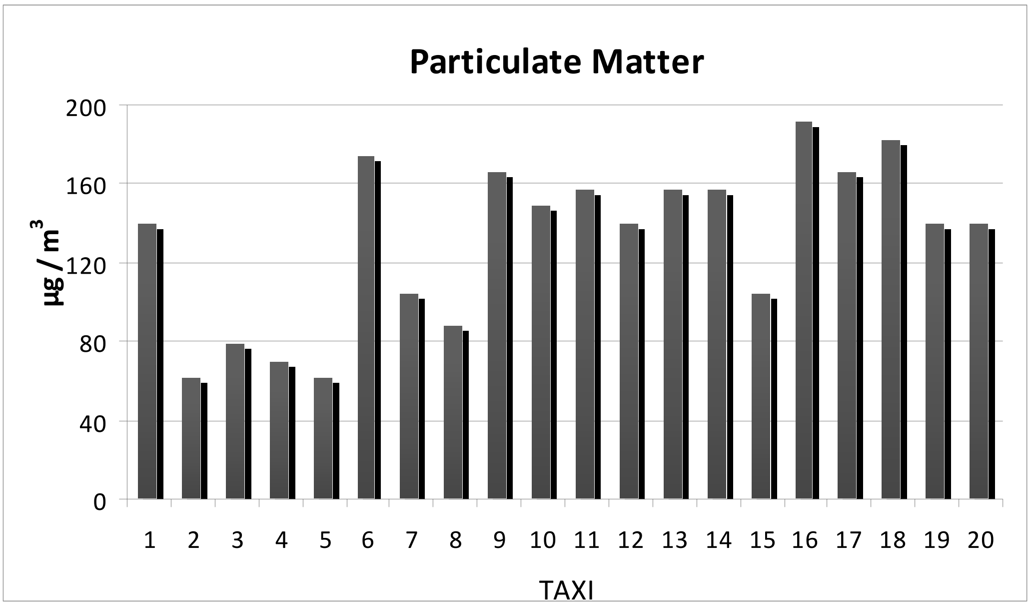

Figure 5. Concentration of Particulate Matter

Particulate matter (PM) pollution consists of solids and liquid droplets of up to 10 micrometers in diameter suspended in the air. Exposure to even low levels of PM can cause nasal congestion, sinusitis, throat irritation, coughing, shortness of breath and chest discomfort. Medical studies have associated exposure to elevated PM10 levels with the aggravation of existing respiratory conditions, including asthma, and more serious medical problems.

Figure 5 shows the concentration level of particulate matter in all the taxicabs. The highest recorded particulate matter concentration of 191 $\mu g/m^3$ in taxi 16 may be due to the poor maintenance of its air conditioning system as well as pollution coming from the vehicles surrounding the taxi. The lowest particulate matter concentration was found in both taxis 2 and 5, each with 61 $\mu g/m^3$. The range of values of particulate matter concentration detected is comparable to those found in a study by Joop H. van Wijnen, et al. in 1995. Their research shows that PM10 levels inside vehicles on busy streets in Amsterdam ranged from 90 to 194 $\mu g/m^3$. In tests conducted on congested highways with stop-and-go traffic, in-car PM10 levels ranged from 120 to 139 $\mu g/m^3$. Concentrations during tests on a rural route ranged from 71 to 166 $\mu g/m^3$.

The drivers were interviewed by the researchers and were asked about the common illnesses or discomforts they feel while driving the taxi. The usual complaints were sleepiness, headaches, skin allergies and dry throat.

The highest concentrations of the contaminants included in this study (except nitrogen dioxide and sulfur dioxide) were all found in taxicab 16. Upon close observation, relatively low in-vehicle pollution was detected in new and properly maintained taxicabs compared to dirty and older-model taxicabs. Simple activities such as regular cleaning and proper maintenance may reduce the level of in-car pollution. With the results of this study, the commuting public can be informed regarding the health hazards associated with poor interior air quality in transport microenvironments. Moreover, companies responsible for converting diesel/gasoline to LPG system may improve their conversion process so that possible leaks are minimized or prevented.

6. CONCLUSION

There was no trace of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) found in all the taxicabs tested. Carbon dioxide (CO_2) concentrations in all the taxicabs exceeded the acceptable limit of 1000ppm based given by the ASHRAE Standards and the Hong Kong Indoor Air Quality Objective. However, only nine out of the twenty taxicabs passed the acceptable carbon dioxide (CO_2) level of 5000 ppm set by the Occupational Safety and Health Center of the Department of Labor and Employment. The concentration of carbon monoxide inside all the taxicabs was within the acceptable limit of 50 ppm set by the Occupational Safety and Health Administration (OSHA). Butane concentrations passed the acceptable level of 1000 ppm based from OSHA and the American Conference of Governmental Industrial Hygienists Standards.

There is evidence of high levels of biological contaminants inside some of the taxicabs based on the large number of colonies that formed on the tryptic soy agar media. But generally, the concentration of biological contaminants in most taxis was within the 1000 cfu/m^3 limit set by the ACGIH Standards.

Sixty percent (60%) or 12 out of 20 taxis had particulate matter concentrations within the 150 $\mu g/m^3$ limit set by the National Ambient Air Quality Standards (NAAQS) and the United States Environmental Protection Agency (USEPA). The high particulate matter concentrations may be attributed to poor and/or defective air-conditioning system of the taxicabs, as well as the volume of the surrounding vehicles spewing thick clouds of smoke.

Dry throat, headache, sleepiness, dry skin, and skin allergy were the most common discomforts cited by the drivers. Pollution inside the taxicabs, over-fatigue, and pollution from outside were the probable causes of these discomforts.

7. RECOMMENDATION

To further improve indoor air quality studies particularly in surface transportation, the following recommendations are given:

- The use of other sampling methodologies such as gas chromatography for determining chemical contaminant concentration
- An extensive study on the conversion to or installation of an LPG fuel system
- The inclusion of other contaminants in the assessment of the interior air quality of LPG-powered vehicles.
- Development of standards in order to establish acceptable levels for the concentration of chemical and biological contaminants, and particulate matter, especially for surface transportation.

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