



Faculty of Mechanical Engineering

**INVESTIGATION OF INDOOR AIR QUALITY FOR ENCLOSED
SPACE APPLICATION USING ELECTRIC-POWERED MINI
EXCAVATOR**



Mohd Asyraf bin Rawi

Master of Mechanical Engineering (Automotive)

2016

**INVESTIGATION OF INDOOR AIR QUALITY FOR ENCLOSED SPACE APPLICATION
USING ELECTRIC-POWERED MINI EXCAVATOR**

MOHD ASYRAF BIN RAWI

**A report submitted
in fulfillment of the requirements for the degree of
Master of Mechanical Engineering (Automotive)**



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitle “Investigation of Indoor Air Quality for Enclosed Space Application Using Electric Powered Mini Excavator” is the result of my own research except as cited in the references. This report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature

:

Name

: MOHD ASYRAF BIN RAWI

Date

:

10.4.2017
او 10.4.2017

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment of Master of Mechanical Engineering (Automotive)



Signature



Supervisor Name : DR. AHMAD ANAS BIN YUSOF

Date : 10 April 2017
اونو 17 2017 تي 4 10 كنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

To my beloved mother, father, my wife, and my son



ABSTRACT

This study investigates the indoor air quality for enclosed space application using electric powered mini excavator. The main content of this study is the indoor air quality for enclosed space application that is caused by mini excavator which is powered by gasoline engine and by electric motor. The impacts of indoor air quality in this enclosed space room are ultimately determined by levels of contaminants and comfort parameters (i.e. temperature, carbon dioxide and carbon monoxide). There are a number of relationships that could be useful in discussing temperature, carbon dioxide and carbon monoxide and indoor air quality, such as the impact of carbon dioxide to a worker (i.e. low comfort level, body odor) and the impact of carbon monoxide to a worker (i.e. slight headache, cardiovascular effect, etc.). In this study, carbon dioxide and carbon monoxide have been used as an indicator of indoor air quality due to both its use as tracer gas for air change rate estimation. The study has been conducted on same enclosed space room with different type of mini excavator. If air quality and comfort are appropriate for running mini excavator powered by electric motor (according to WHO guidelines) and, on the other, to establish whether mini excavator powered by gasoline engine exceeds a recommended exposure limit (according to WHO guidelines), acquired data is useful in defining indoor air quality.

اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Kajian ini mengkaji kualiti udara dalaman untuk situasi ruang yang tertutup menggunakan jengkaut berkuasa motor elektrik. Kandungan utama kajian ini berkenaan kualiti udara dalaman untuk keadaan ruang yang tertutup yang merupakan jengkaut yang dikuasakan oleh enjin petrol dan motor elektrik. Kesan kualiti udara dalaman di ruang yang tertutup ditentukan oleh tahap pencemaran dan parameter keselesaan iaitu (suhu, karbon dioksida dan karbon monoksida). Terdapat beberapa hubungan yang boleh dikaitkan dalam membincangkan suhu, karbon dioksida dan karbon monoksida dan kualiti udara dalaman ini, seperti kesan karbon dioksida kepada pekerja (iaitu tahap keselesaan yang rendah, bau badan) dan kesan karbon monoksida seorang pekerja (iaitu sakit kepala, kesan kardiovaskular, dan lain-lain). Dalam kajian ini, karbon dioksida dan karbon monoksida telah digunakan sebagai petunjuk kualiti udara dalaman kerana kedua-dua kepada penggunaannya sebagai gas penyurih untuk kadar perubahan udara anggaran. Kajian ini telah dijalankan ke atas ruang yang tertutup dengan pelbagai jenis jengkaut. Jika kualiti udara dan keselesaan adalah sesuai untuk menjalankan penggali mini dikuasakan oleh motor elektrik (mengikut garis panduan WHO) dan, untuk menentukan sama ada penggali mini dikuasakan oleh enjin petrol adalah melebihi had pendedahan yang disyorkan (mengikut garis panduan WHO), yang diperolehi data berguna dalam menentukan kualiti udara dalaman.

اونيورسي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACKNOWLEDGEMENTS


I would like to take this opportunity to express my sincerest gratitude to my main supervisor, Dr. Ahmad Anas bin Yusof from Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his guidance, support, and constant encouragement during my research and to Assoc. Prof. Dr. Noreffendy Bin Tamaldin for the support and encouragement. I also acknowledge the Majlis Amanah Rakyat (MARA) for their financial support and encouragement for this opportunity to further our study.

I also thank my colleagues at the Automotive Department, Kolej Kemahiran Tinggi MARA Masjid Tanah Mohd Rasyidi b Rizuan, Azhar bin Ibrahim, Shahril Izwan b Haris, Ammar Alfaiz bin Mustaffa Al-Bakri, Ahmad Shahizam b Abdul Rahim, Faizal Azli b Jumaat, Mohd Roziani bin Md Nafiah, Mohd Al-Sideque bin Zainuddin and Mohd Saiful bin Md Sukardi for their outstanding collaboration during our study and also for being a very good friend and partner during my research. Thanks again for providing an enjoyable study environment.

Finally, my deepest grateful and thanks go to my parent, Rawi bin Mohd Ali and Che Robiah binti Che Mat, my life partner, best friend and wife Rafhanah binti Ramliy, my son Luqmanul Hakim. Thanks for be patient during my study. Not to forget, special thanks to my brother and sister Muhammad Hanif bin Rawi, Mohd Faiz b Rawi, Najwa binti Rawi, Mohd Fatihi Ikram bin Rawi and Muhammad Herman bin Rawi for giving me a real support, pray, and all they have. You're the best family I could have. _____

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF APPENDICES	x
LIST OF SYMBOLS	xi
 <p>UNIVERSITI TEKNIKAL MALAYSIA MELAKA</p>	
CHAPTER	
1. INTRODUCTION	1
1.1. Introduction	1
1.2. Problem Statement	5
1.4. Research Objectives	5
1.5. Scope of Research	5

2.	LITERATURE REVIEW	7
2.1.	Indoor Air Quality	7
2.1.1	Type of Pollutants	9
2.1.2	Sources of Air Pollutions	10
2.2.	Thermal Comfort	10
2.3.	Carbon Dioxide	13
2.3.1	Modelling air change in indoor environments	15
2.3.2	Tracer Gas Method	16
2.4.	Carbon Monoxide	20
2.4.1.	Permissible Exposure Limit (PEL)	21
2.4.2.	Carbon Monoxide Poisoning	22
2.4.3.	Chemical and Physical Properties	23
2.4.4.	Monitoring and Measurement Procedures	24
2.5.	Enclosed Space	25
3.	METHODOLOGY	28
3.1.	Introduction	28
3.2.	Flow Chart	29
3.3.	Design of Experiment	30
3.4.	Mini Excavator	32
3.4.1	Excavator Kobelco SS60	32
3.4.2	Electric Excavator Kobelco SS60	34
3.5	Indoor Air Quality Meter	35
4.	RESULT AND DISCUSSION	38
4.1.	Introduction	38

4.2. Gasoline Mini Excavator Result	38
4.3. Electric Mini Excavator Result	41
4.4 Comparison of Gasoline and Electric Mini Excavator	44
4.5 Factor affecting indoor air CO concentrations	47
5. CONCLUSION	49
5.1. Conclusion	49
5.2. Recommendation for Future Work	50
REFERENCES	51



LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Overview of OSHA Standard	22
3.1	General excavator specifications	33
3.2	Specifications of IAQ Meter Model 7545	37



LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Example excavator used in enclosed space	2
2.1	Typical daily variation of indoor CO ₂ concentration level (black solid line). Grey solid line refers to relative humidity levels (RH%) on right y-axes. While short dashed lines and long dashed lines refers to the beginning and ending of lessons, respectively	18
2.2	CO ₂ concentration measured inside the train of line 2	19
2.3	IAQ meter Model 7545	20
3.1	Flow chart of experiments	29
3.2	Top view experiment layout for gasoline and electric mini excavator	31
3.3	Side view experiment layout for location of IAQ meter	31
3.4	Excavator Kobelco SS60	32
3.5	Electric Excavator Kobelco SS60	34
3.6	Hydraulic Power Unit	35
3.7	Indoor Air Quality Meter	36
4.1	CO ₂ concentration level	39
4.2	CO concentration level	40
4.3	Temperature level	41
4.4	CO ₂ concentration level	42

4.5	CO concentration level	43
4.6	Temperature level	43
4.7	Carbon dioxide and carbon monoxide comparison of gasoline and electric excavator	45
4.8	Temperature comparison between gasoline and electric excavator	46



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Testing Data for Mini Excavator Powered By Gasoline Engine	59
B	Testing Data for Mini Excavator Powered By Electric	65



LIST OF SYMBOLS

C_0	-	Non Zero Concentration
C_a	-	Outdoor Air Concentration
C_i	-	Indoor Air Concentration
V_R	-	Total Volume
CO	-	Carbon Monoxide
CO ₂	-	Carbon Dioxide
IAQ	-	Indoor Air Quality
COHb	-	Carboxyhemoglobin
E	-	Closed Room per Time Unit
Q	-	Room per Unit Time
$Q(t)$	-	Air Source
REL	-	Recommended Exposure Limit
ppm	-	Part per Million
t	-	Time
$\lambda(t)$	-	Rate of Air Changing



اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background

World Health Organization (2010) reported that, indoor air quality, especially in a place very heavy emphasis on the point, because people spend more time inside than outside of the house. Polluted air in an enclosed area will usually be worse than outdoor. According to ASHRAE, Standard 62. (2001) usually place of work is owned by a company which is protected by the labour law, the policy is not applicable to this (i.e., study place, market, swimming pool, shop, clinics).

Mendel et al. (2005) reported that the children, adults and the elderly are usually the most susceptible and have a great potential to expose to danger from indoor air quality. According to Mendel, approximately 25% - 30 % of school students starting from elementary school to middle school to spend time in the school building. Furthermore, productivity and focus of the students will also be affected as a result of air quality that is very dirty and will cause the temperature increases, the air becomes humid and high carbon dioxide concentration.

Productivity and attention during the work will have a major impact on business costs, and indirectly associated with convenience while working. Comfort is not the same work among the workers and other employees, because at work is closely related to the person's physical and psychological. It depends on many factors including the type of clothing that is in use, the type of activities including a set of environmental conditions of the workplace. Usually, greatest scorer range is 70% - 85% of the number of employees.

The feature - which measure included noise, vibration, ventilation, air velocity, humidity, and temperature. These characteristic are the most important to measure employees satisfaction during working and also will effected their psychological. If employees psychological is good, of Couse productivity will directly increased.

Most of the heavy machinery that uses fuel, petrol and diesel has been releasing large amounts of carbon dioxide during the operating lifetime of use. Campaign reduction in fuel consumption of petrol and diesel in particular has a major impact on the reduction of carbon emissions. And with this campaign, there have vehicles using the hybrid system more efficient and more environmentally friendly when compared with systems using 100% fuel (Hiroaki Inoue, 2008). Air pollution increasing global temperature has become a major issue which is very serious in the present. Figure 1.1 below shows the example of excavator working in a building with enclosed space area. As a result of these, enclose space working area of these excavator will be filled with CO₂ pollution, temperature surrounding this area will be increase and a poisonous gas such as carbon monoxide that is a by-product of incomplete combustion.

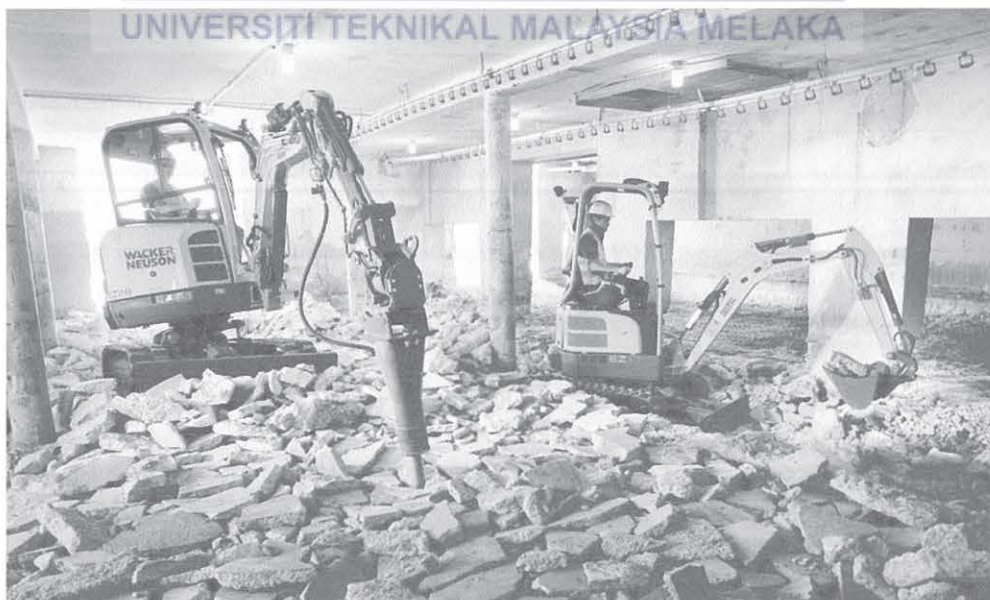


Figure 1.1: Example excavator used in enclosed space.

By assessing the carbon dioxide readings indoor air content of an enclosed area, ventilation and indoor air quality can be determined precisely (ASHRAE, Standard 62-2001). but with the passage of carbon dioxide alone is not sufficient to provide an indication of good indoor air quality, and regularly assesses the carbon dioxide, it can be used to assess the acceptability of a space in terms of people comfort and body odour (the level of carbon dioxide will usually be associated with a very moist air). Take one example, the carbon dioxide produced by the movement of the residents of the area a closed environment: the rate of air exchange can be assessed by the method draws air from outside the region, can reduce indoor air concentrations of carbon dioxide. This shows clearly that natural ventilation is not effective and not adequate to ensure that carbon dioxide levels remain below acceptable limits include ingredients that are very dangerous, whether from within the room itself or from internal resources itself.

Air humidity and temperature is closely associated with comfort, because there are many complaints regarding the freshness of air is not satisfactory. Most of the problems are not satisfactory due to the heating system is not maintained and not maintained properly, the ventilation system is inefficient and faulty air conditioning system. In addition, the use of chemical detergents, disinfectant products and aerosol products also affect indoor air quality. Unsuitable temperature conditions along with moist air that affects this issue terumatanya regarding comfort while working.

The presence of carbon monoxide can not be realized because of the air is odorless, colorless and it went unnoticed by the workers (Langston et al., 2010) and this gas is likely to be released into the environment from natural sources or machinery. This gas is also produced from incomplete combustion of fuel such as gasoline, wood, coal, natural gas and kerosene (WHO, 2010). Most industrial plants in the area, the vehicle has an internal combustion engine and the industry is said to have a major impact on the level of carbon

monoxide. However, the air quality in the building is heavily influenced by cigarette smoke, burning wood stoves, fireplaces and other fossil fuel burners (Chowdhury et al., 2013). Exposure to high readings of carbon monoxide in an enclosed space is very rarely encountered and if it happens it is likely that someone close to sources that emit carbon monoxide itself (Chaloulakou and Mavroidis, 2002). Readings of carbon monoxide gas in an enclosed space, usually not exceeding 30 ppm with regard to the common environment and with natural and effective ventilation system (ATSDR, 2009). If there are no sources of carbon monoxide in an enclosed space, for example in the home, in libraries and in the office, from external sources can also affect internal reading concentration of carbon monoxide (Zhong et al., 2013) with indoor to outdoor (I/O) ratios generally around 1 (WHO, 2010).

If a person has been exposed to carbon monoxide gas in a certain period of time, it will affect very dangerous to the respiratory system of a person, especially to the lungs of a human system. It also depends on the current health of an employee. If an employee was having trouble breathing system then it will impact very badly (WHO, 2010; Reboul et al., 2012). Among the significant impact the results of overexposure to carbon monoxide is a gas, carbon monoxide reacts with hemoglobin blood molecules and will produce carbonxyhemoglobin (COHb); the effect it will cause the supply of oxygen to the brain and organs - other organs in the body will decrease. Reading the concentration in the blood has been used as a guide to health if an employee is exposed to carbon monoxide. The result is a range of symptoms has been produced as a result of different concentrations of COHb in the blood of a person. Typically, the feature - and the symptoms of carbon monoxide poisoning will exist in COHb reading between 3 to 24%. Conclusion, symptoms of carbon monoxide poisoning to exist in COHb% more than 3 percent in the blood of someone who has been exposed (ATSDR, 2009).

1.2 Problem Statement

When using excavators indoors, there are a few things to consider. Firstly, the space of an enclosed location is limited. Usually this means usage of smaller sized machines. Secondly, when working in enclosed spaces ventilation is usually weak. Additional ventilation has to be built for the exhaust gas outlet. This means that work site manager has to make plans and build additional ventilation, thus makes the use of an excavator indoors considerably more expensive than outdoors. The need of additional ventilation could in some cases be avoided if the work machines were powered with non-combustible engines. Agriculture, construction and general industry employees are exposed to carbon monoxide (CO) when using fuel-burning equipment indoors or in enclosed spaces. This toxic gas may become dangerously elevated if the equipment is not properly maintained and ventilation is inadequate. Industrial lift trucks, automobiles, aerial lifts, floor burnishes, generators, power washers, compressors, concrete cutters and concrete trawlers are some examples of fuel-burning equipment that emit this toxic gas. This study aims to investigate the indoor air quality for enclosed space application using electric – powered mini excavator.

1.3 Research Objective

The objective of the study is:

1. To investigate the differences of Indoor Air Quality (IAQ) affected by electric powered and gasoline mini excavator.

1.4 Scope of Study

The types of machines that will be used for this testing are as follows:

- a. Gasoline type mini excavator (Kobelco).
- b. Electric powered mini excavator convert from gasoline type mini excavator

The types of investigation testing are as follows:

- a. Comfort issues and Productivity: Common measurable characteristic of comfort are temperature and air ventilation that is carbon dioxide.
- b. Health and safety issues: Common measurable characteristic of health and safety issues is carbon monoxide.

Several parameters must be set for both testing above, the parameter are as follows:

- a. The distance of Indoor Air Quality meter is located 20 feet from the source.
- b. The height of Indoor Air Quality meter:
 - i. Floor level.
 - ii. 160 cm from the floor.
 - iii. All measurement will be taken from 2pm – 5 pm.

Then, the effect of comfort issues, productivity and safety and health issues can be analyse using graph from Microsoft excel. Comparison between both will indicate how significant the effect of indoor air quality by gasoline driven and electric powered mini excavator.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Air Quality

Rao (1996) reported that indoor air quality readings are too low has been confirmed as one of the five most significant risk to the health of workers at work. According to Heinsohn. (2003), the Centers for Disease Control and Prevention (CDC) estimated that most people in the United states spend about 90 percent in the building. on average, as many as 40 hours a week of time that has been allocated in an organization in an office building. In addition to working, between the activities undertaken during the office is drinking, eating, chatting, meeting in a closed environment where the ventilation system taking fresh air and recirculated air plus. Due to this situation, some experts think the future will be more workers who will suffer the effects of pollution in the building compared with outdoor air pollution is caused.

Each building has its own unique design. Air quality is determined by the design of the building, and if there is renovation work it will also indirectly impact on air quality. In addition, among the factors that affect the quality of the air density is the number of employees and the type of activities carried out in the building. Indoor air quality problems can result from a variety of sources and a combination of several factors. Ventilation air system which can lead to bad air quality is not good especially with the building design such severe conditions that prevent the entrance of the building's roof fresh air, the location of buildings that do not fit and so on.

Most of the problems related to indoor air quality caused by the air conditioning system is not maintained according to schedule and cause the temperature inside the building is not comfortable, the air humidity in the building is too dry or too humid especially with the environmental conditions that have air that is polluted and this will further improve air quality readings are dirty. Usually when the humidity is high, an employee would feel uncomfortable while working on adding more body will smell.

According to Daisey et al. (2003) the ventilation system indirectly related to indoor air quality (IAQ) will impact indirectly on the performance of student learning in school. Furthermore, a detailed study has been carried out have shown that the existence of health problems due to air quality system that is not clean. A thorough examination has been conducted and has shown a negative result.

Arif et al. (2016) reported in his review journal that, people has struggled relentlessly from the past to the present to keep the area around their work in a comfortable condition. In determining the appropriate method to evaluate the comfort, health workers have taken a very important thing. If the building design or errors in their design a building that could lead to labour problems or negative effects that can create disease, then it is a very dangerous and must be taken seriously. Refer to the instructions specified ASHRAE (ASHRAE, 2010), studies show that 80-90% of most workers and people spend their daily lives in a closed room, and the results of these studies have clearly shown that the comfort and health of workers is a factor - a factor intertwined with the design of the building. As a result of this there is the impact of the scientific phenomena academic and health-related researchers showed interest to study in more detail in this field. The results of the observations of experts - specialists in the field state that the effect of discomfort while working in a closed room will cause the affected employee productivity and decreases. (EPA, 2000).