



**UNIVERSITI PUTRA MALAYSIA**

**DETERMINATION OF OPTIMUM LOCATION FOR  
CARBON MONOXIDE DETECTORS IN CAR CABINS**

**HAMIDREZA GHEZAVATI**

**FK 2011 46**

**DETERMINATION OF OPTIMUM LOCATION FOR  
CARBON MONOXIDE DETECTORS IN CAR CABINS**

**By**

**HAMIDREZA GHEZAVATI**



**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfillment of the Requirement for the Degree of Doctor of Philosophy**

**June 2011**

## DEDICATION

This thesis is dedicated to the soul of my father who passed away recently, my paternal uncle and the uncle who died from carbon monoxide poisoning, and to my beloved family, my mother, my wife SIMIN and my son, ARMIN and daughter, AZIN who always understand and give me loving support.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**DETERMINATION OF OPTIMUM LOCATION FOR CARBON MONOXIDE DETECTORS IN CAR CABINS**

By

**HAMIDREZA GHEZAVATI**

**June 2011**

**Chairman: Associate Professor Ir Nor Mariah bt. Adam, PhD**

**Faculty: Engineering**

There is limited study on CO concentrations exposure in car cabin in Malaysia. The specific objectives of this study are: (i) to determine the entry routes of CO in a stationary car (ii) to determine entry for moving car on congested, less congested and not congested roads (iii) for use results from objective (i) and (ii) as input parameters on computational fluid dynamics (CFD) to predict optimum location of detector. The car was driven with different modes of air conditioning: recirculation and fresh air intake at two different times of day (morning and evening) from September through December 2008. The CFD simulations using the realizable k- $\epsilon$  model was used to predict optimum location of detector in car cabin. The simulation result was then verified via experimental data from literature. The k- $\epsilon$  model is the most common turbulent model due to its accuracy for this type of conditions.

More than 84 percent of CO entry into car cabin was through the vent in the rear trunk and through the diffuser of the air-conditioning system; i.e. 16 percent cabin

leak cracks, holes, gaps or other openings in the car cabin. The highest mean CO exposure was experienced for the recirculation mode, location Middle Ring Road II (MRRII), and time of day pm and am, with mean CO concentrations of 19.7 ppm and 18.5 ppm respectively for average of 70 trips. Experimental measurements on CO level was done in WIRA car cabin, the fan of the car drove the flow through the front diffuser in three levels: high, medium and low flow rates equal to 0.0587 kg/s , 0.0443 kg/s and, 0.0293 kg/s, respectively. The experimental data was used to verify the simulation results. Three-dimensional CFD using FLUENT 6.3 showed that the optimal detector location was found to be in the middle of ceiling where the detector can measure the highest CO in the least amount of time and for easy maintenance.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENENTUAN LOKASI OPTIMUM UNTUK PENGESAN KARBON MONOKSIDA DI DALAM KABIN KABIN KERETA**

Oleh

**HAMIDREZA GHEZAVATI**

**Jun 2011**

**Pengerusi: Profesor Madya Ir Nor Mariah bt. Adam, PhD**

**Fakulti: Kejuruteraan**

Kajian tentang kepekatan karbon monoksida (CO) di dalam kabin kereta adalah sangat terhad di Malaysia. Objektif spesifik kajian merangkumi: (i) Penentuan laluan masukan CO ke dalam kereta sedang berhenti (ii) Kemasukan CO semasa kereta bergerak di jalan sesak, lalulintas, kurang sesak dan tiada kesesakan lalulintas (iii) keputusan dari objektif (i) dan (ii) digunakan sebagai parameter input untuk kerja simulasi menggunakan dinamik bendalir berkompputeran (CFD). Kereta juga dipandu dengan mod penghawa dingin kitaran semula dan mod masukan udara segar pada waktu pagi dan petang dari bulan September hingga Disember 2008. Kerja simulasi CFD adalah menggunakan model *realizable* k- $\epsilon$  untuk meramal lokasi optimum pengesan CO di dalam kabin kereta. Keputusan simulasi disahkan dengan keputusan data eksperimen literatur. Model k- $\epsilon$  merupakan model keadaan bergelora yang sering digunakan kerana kejituannya untuk keadaan demikian.

Lebih 84 peratus masukan CO ke dalam kabin kereta adalah melalui ruang di dalam tempat penyimpanan belakang dan masukan sistem penghawa dingin iaitu 16

peratus melalui celahan, retak, lubang, rekahan atau lain-lain ruang di kabin kereta. Pendedahan CO yang paling tinggi disukat adalah pada mod kitaran semula di Jalan Lingkaran Tengah II (MRR2), pada waktu pagi dan petang dengan min CO masing-masing 19.7 ppm dan 18.5 ppm untuk 70 kali laluan. Pengukuran eksperimen untuk nilai CO yang dijalankan di kereta Wira melibatkan kipas mendorong aliran udara masukan pada mod tinggi, sederhana dan rendah masing-masing bernilai 0.0587 kg/s, 0.0443 kg/s and, 0.0293 kg/s. Data daripada eksperimen mensahihkan keputusan simulasi. Hasil keputusan CFD FLUENT 6.3 tiga dimensi menunjukkan lokasi optimum pengesan adalah di tengah-tengah siling kabin kereta yang mana tahap maksimum CO sering berlaku, memudahkan bacaan pengesan dan mudah menjalankan kerja penyenggaraan.

## ACKNOWLEDGEMENTS

Praise is to God, Who has spurred me on through his command: ‘Read! And thy Lord is Most Bountiful, He Who taught (the use of) the Pen’.

I am heartily thankful to my supervisor, **Associate Professor Ir Dr Nor Mariah bt. Adam**, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

Secondly my gratitude goes to my co supervisor Dr. Abdul Aziz Jaafar. He managed to keep the fragile balance between providing guidance and freedom. This allowed me to make mistakes, discover many aspects of science, and to explore a variety of different topics.

Thirdly, special thanks to Prof. Mahmood Yaghoubi .He possessed the invaluable ability to provide – within a blink of an eye - excellent feedback to a sciatic problem, and re-establish both condense and motivation.

My deepest appreciation to my father, mother, brothers, sisters and my in-law family members for their constant encouragement and support during the course of the study.



My heart-felt thanks and appreciation goes to my son and daughter Armin and Azin and my wife Simin for their sacrifice, patience, understanding, help and encouragement throughout the study.

I would like to thank all students and members of the ITMA, Universiti Putra Malaysia, laboratory, past and present, for their friendship, support and advice.

I also give special thanks to Mr Ali Nong and Madam Roslina for their valuable professional advice upon consultation.

I thank Dr. Mohd Khairol Anwar, the Department of Mechanical and Manufacturing Engineering, and staff of Graduate School of Universiti Putra Malaysia for helping me in one way or another towards the completion of this study.

I wish to express my thankfulness to my friends, engineer Dr .Shahin Akbarpor, Behroz Arabi, Mehrdad Arabestani, Asghare Pishghahi, Mehdi Gheiji and Amir Pakravan, and Mohamad Ghilaki for their encouragement throughout my study. Lastly, I offer my regards and blessings to all of those who supported me in any way in the completion of the project.

I certify that an Examination Committee has met on 28 June 2011 to conduct the final examination of Hamid Reza Ghezavati on his thesis entitled “DETERMINATION OF OPTIMUM FOR CARBON MONOXIDE DETECTOR IN CAR CABIN ” in accordance with the University colleges Act 1971 and the Constitution of Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Chairman, PhD,PEng.**

Professor Mohd Sapuan Bin Salit  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Examiner 1, PhD.**

Associate Professor Tang Sai Hong  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Examiner 2, PhD.**

Dr Rimfiel Bin Janius  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**External Examiner, PhD.**

Professor Masjuki Hj. Hassan  
Faculty of Engineering  
Universiti of Malaysia  
(External Examiner)

---

**Noritah Omar, PhD**

Associate Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia  
Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree Doctor of Philosophy.

The members of the Supervisory Committee were as follows:

**Nor Mariah bt. Adam, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Abdul Aziz Jaafar , PhD**  
Senior Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Mahmood Yaghoubi, PhD**  
Professor  
Faculty of Mechanical Engineering  
Shiraz University  
(Member)

---

**HASANAH MOHD GHAZALI, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia  
Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



**HAMIDREZA GHEZAVATI**

Date:

## TABLE OF CONTENTS

	<b>Page</b>
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENT</b>	vii
<b>APPROVAL</b>	ix
<b>DECLARATION FORM</b>	xi
<b>LIST OF TABLES</b>	xv
<b>LIST OF FIGURES</b>	xvii
<b>LIST OF ABBREVIATIONS</b>	xxi
 <b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	
1.1 Introduction	1
1.2 Problem Statement	4
1.3 Hypothesis	7
1.4 Research Objectives	7
1.5 Assumption	8
1.6 Scope and Limitation	8
1.7 Layout of Thesis	8
<b>2 LITERATURE REVIEW</b>	
2.1 Indoor Air Quality	9
2.1.1 Contaminant Source	12
2.2 Measurements Used to Determine Air Quality	13
2.2.1 Occupant Surveys	13
2.2.2 Ventilation Rate	13
2.2.3 Infiltration	14
2.3 Passenger Exposure to CO from Motor Vehicles	16
2.3.1 Car Cabin CO Exposure Levels	18
2.3.2 Carbon Monoxide in Malaysia	21
2.4 Airflow and Carbon monoxide Transport in Car Cabins	23
2.4.1 Experimental Study	23
2.4.2 Numerical Study	27
2.4.3 Work on Computational Fluid Dynamics (CFD)	27
2.5 Study of Carbon Monoxide Detector Placement	29
2.6 Closure	32
<b>3 METHODOLOGY</b>	
3.1 Introduction	33
3.2 Experiment in Automotive Laboratory	35
3.2.1 Determination of Leakage Points on Stationary Car Cabin	36

3.2.2	Evaluate Leakage Point on the Car Cabin	40
3.2.3	Infiltration Rate of Stationary Car Cabin and Chamber	42
3.2.4	Measuring Car Cabin CO Concentration in Proton Wira Car	44
3.3	Road Tests	49
3.4	Computational Fluid Dynamics (CFD) Analysis	55
3.4.1	Problem Description	55
3.4.2	Numerical Procedure	57
3.4.4	Discretization of General Scalar Transport Equation	66
3.4.5	Solver Types	68
3.4.7	Pressure-Velocity Coupling	70
3.4.8	Boundary Conditions	75
3.4.9	Material	78
3.4.10	Residual	78
3.4.11	Mesh and Time Step Independent Study	80
3.4.12	Comparison between Experimental and Numerical Results	80
3.5	Assumption	81
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	
4.1	Experiment at Automotive Laboratory	82
4.1.1	Introduction	82
4.1.2	Parametric Study in Automotive Lab	83
4.1.3	Evaluate Leakage Points on Car Cabin	84
4.1.4	Measuring the Air Leakage on Car Cabin	85
4.2	Effect of Parameter On Car Cabin CO Concentration	87
4.2.1	CO Concentration in Malaysia	87
4.2.2	Car Cabin CO Concentration to Average Wind Speed	93
4.2.3	Outdoor and Car Cabin CO Level Relationship	93
4.2.4	Car Cabin CO Concentration to Car Speed Relationship	98
4.2.5	Car Cabin and Outdoor Concentration	100
4.3	Fluent Simulation	101
4.3.1	Validation of CFD	102
4.3.2	Distribution of CO in Car Cabin	106
4.3.3	Effect of air flow Rate on Car Cabin CO Concentration	120
4.3.4	Comparison of Experimental and Numerical Results	121
4.3.5	Comparison between k-ε Models	126
<b>5</b>	<b>CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH</b>	
5.1	Introduction	128
5.2	Conclusion	129
5.3	Recommendation for Future Research	132
	<b>REFERENCES</b>	134
	<b>APPENDIX 1</b> Number of Motor Vehicles Registration in Kuala Lumpur	144
	<b>APPENDIX 2</b> Navier Stokes Equation of Flow	145

**APPENDIX 3** Turbulance Models  
**BIODATA OF STUDENT**  
**LIST OF PUBLICATIONS**

147  
153  
154



© COPYRIGHT UPM