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REDUCING EXHAUST EMISSIONS FROM PASSENGER CARS BY USING THREE-WAY CATALYTIC CONVERTER

Mr.Krissadang Sookramoon

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สภาพการจราจรในกรุงเทพมหานครที่แย่ลงก่อให้เกิดปัญหามลพิษมากขึ้น รถยนต์นั่งส่วนบุคคลที่จดทะเบียนในกรุงเทพมหานครมีปริมาณมากที่สุดในจำนวนยานพาหนะทั้งหมด ไอเสียที่ถูกปล่อยออกมาจากรถยนต์เหล่านี้ก่อให้เกิดอันตรายต่อสุขภาพของประชาชนได้แก่โรคมะเร็งปอด การศึกษานี้เป็นการศึกษาลักษณะการขับขี่ของรถยนต์บนถนนสามเส้นทางในกรุงเทพมหานคร เพื่อหาวัฏจักรการขับขี่ในเมืองและนำวัฏจักรการขับขี่นี้ไปจำลองสภาพการขับขี่บนแชสซีไดนาโมมิเตอร์ จากนั้นทำการวัดและเปรียบเทียบมลพิษในไอเสียของรถทดสอบสามคัน โดยติดตั้งและไม่ติดตั้งเครื่องกรองไอเสียแบบสามทางซึ่งเส้นทางที่เลือกได้แก่ เส้นทางที่ 1 ฟิวเจอร์ปาร์ครังสิต-สนามบินดอนเมืองระยะทาง 8.7 กม., เส้นทางที่ 2 ฟิวเจอร์ปาร์ครังสิต-อนุสาวรีย์หลักสี่ ระยะทาง 14.7 กม. เส้นทางที่ 3 อนุสาวรีย์หลักสี่-มหาวิทยาลัยเกษตรศาสตร์ ระยะทาง 4.5 กม.รถยนต์ที่ใช้ทดสอบเป็นรถยนต์มิตซูบิชิแลนเซอร์ขนาดเครื่องยนต์ 1.5, 1.6, 1.8 ลิตร ตามลำดับโดยมีระยะทางวิ่ง 80,812 กม., 67,000 กม., และ 23,465 กม.ตามลำดับ การศึกษาประกอบด้วย 2 ขั้นตอนคือ ขั้นตอนที่1 หาสภาพการขับขี่บนถนนสามเส้นทางของกรุงเทพมหานครโดยการขับขี่จริง จากนั้นนำวัฏจักรการขับขี่ที่ได้มาจำลองสภาพการขับขี่ในห้อง ปฏิบัติการของบริษัทเอ็มเอ็มซีสิทธิผลจำกัด อ.คลองหลวง จ.ปทุมธานี ขั้นตอนที่2 หาส่วนประกอบของก๊าซไอเสียจากรถทดสอบขณะจำลองการขับขี่บนแชสซีไดนาโมมิเตอร์ โดยทำการวัด HC, CO, NO_x, CO_2, และ TPM โดยใช้เครื่องมือวัดไอเสียที่บริเวณส่วนหลังของ เครื่องกรองไอเสีย

ผลการศึกษาแสดงให้เห็นว่าความเข้มข้นของมลพิษได้แก่ HC , CO, NO_x จากรถยนต์ทดสอบทั้งสามคันมีความแตกต่างกันโดยขึ้นอยู่กับ ขนาดของเครื่องยนต์ ปีที่ผลิต และ ระยะทางวิ่ง มลพิษจากท่อไอเสียของรถยนต์ที่ติดตั้งเครื่องกรองไอเสียแบบสามทางมีปริมาณน้อยกว่ารถยนต์ที่ไม่ได้ติดตั้ง เครื่องกรองไอเสีย นอกจากนี้ผู้วิจัยยังได้เสนอการประเมินค่าเฉลี่ยของมลสารได้แก่ CO HC, และNO_x ที่ปล่อยออกมาจากรถยนต์นั่งส่วนบุคคลในระหว่างปี คศ. 2001-2006 ในกรุงเทพมหานครโดยใช้แบบจำลองทางคณิตศาสตร์และได้เสนอเทคโนโลยีการลดมลภาวะและแนวทางการปรับปรุงคุณภาพอากาศในกรุงเทพมหานครในอนาคตอีกด้วย

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา.........................

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา.........................

KRISSADANG SOOKRAMOON: REDUCING EXHAUST EMISSIONS FROM PASSENGER CARS BY USING THREE-WAY CATALYTIC CONVERTER. THESIS ADVISOR: RANJNA JINDAL, Ph.D. 133 PP. ISBN 974-533-1873-3

HYDROCARBONS (HC)/ CARBON MONOXIDE (CO)/ NITROGEN OXIDES (NO_X)/ CARBON DIOXIDE (CO_2)/ TOTAL PARTICULATE MATTER (TPM)/ DRIVING CYCLE/ DRIVING SIMULATION ON CHASSIS DYNAMOMETER

Traffic density and flow conditions in Bangkok have become progressively worse and consequently air pollution is also becoming more and more serious. Passenger cars are the largest number of the total vehicles registered in the Bangkok Metropolitan Region(BMR). The exhaust gases emitted from the tail pipes of these vehicles are the pollutants, which harmfully affect the human health, especially causing lung cancer. The objectives of this research were: to conduct the driving mode tests along the three traffic routes in BMR to obtain suburban driving cycles; to simulate the driving cycles on chassis dynamometer; and to measure and compare the exhaust gas emissions from three passenger cars equipped with and without three-way catalytic converter.

Three traffic routes in BMR were selected for this study, route 1: Future Park Rangsit - Donmung Airport (distance: 8.7 km), route 2: Future Park Rangsit - Laksi Monument (distance: 14.7 km), and route 3: Laksi Monument - Kasetsart University (distance: 4.5 km). Three test cars selected for the study were Mitsubishi Lancers of engine sizes 1.5, 1.6, and 1.8 L, with the mileage 80,812 km, 67,000 km, and 23,465 km, respectively.

Research methodology included two major parts. The first part involved obtaining the driving cycles along the 3 selected traffic routes in suburban Bangkok area by the test drive runs. Subsequently, the driving cycles were simulated on a chassis dynamometer in the laboratory at the Mitsubishi Motor Corporation Sittipol Co., Ltd. in Klong Luang district of Pathumthani Province of Thailand.

The second part involved determination of exhaust emission gas components for the test cars during the simulated driving cycles on the chassis dynamometer by measurement of: hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X), carbon dioxide (CO_2), and total particulate matter (TPM). The CO, CO_2, HC, and NO_X were measured with the vehicle exhaust analyzer. The samples of exhaust emissions from the 3 test cars were taken from the tail pipes downstream of the catalytic converter.

The results of this study indicated that the concentrations of CO,HC, and NO_X in the exhaust emissions from the three test cars during the simulated driving runs on the chassis dynamometer were different depending on the engine capacity, year of manufacturing, and the mileage. The pollutants in the tail pipe gases of the cars equipped with 3-way catalytic converter were lower than the ones without any control device. In addition to the experimental investigations, vehicular emissions of the key pollutants (such as CO HC, and NO_X) from the passenger cars during the next five year 2001-2006 in Bangkok Metropolitan Region (BMR) were estimated using a mathematical model. Finally, a number of technologies for reducing exhaust emissions and policy measures were proposed to improve the air quality of Bangkok Metropolitan Region (BMR) in the future.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา K. Sakrana........
ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา........

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Krissadang Sookramoon

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List of Abbreviations

Abbreviation		Description
A/F	=	Air / Fuel Ratio
CO	=	Carbon monoxide
DOSTE	=	Department of Science, Technology and Environment
EPA	=	Environmental Protection Agency
g/km	=	Gram per kilometer
HCs	=	Hydrocarbons
MOSTE	=	Ministry of Science, Technology and Environment
mg/m^3	=	Milligram per cubic meter
NO	=	Nitric Oxide
NO_2	=	Nitrogen Dioxide
NO_x	=	Nitrogen Oxides
O_3	=	Ozone
Pb	=	Lead
PCD	=	Pollution Control Department
PM_{10}	=	Particulate Matter(with particle size $\leq$ 10 μm)
ppm	=	Parts per million
rpm	=	Revolution per minute
SO_2	=	Sulphur Dioxide
TPM	=	Total Particulate Matter
TSP	=	Total Suspended Particulate Matter
Vol	=	Volume
e_{ij}	=	Exhaust emission factor
m_{ij}	=	Mass of component i in phase j of US-75 driving cycle Speed
v	=	Velocity
Δ	=	Difference
Δp	=	Differential pressure
ε	=	Coefficient of expansion

List of Abbreviations (Cont.)

Abbreviation		Description
ε_{kjv}	=	Vehicle emission
Θ_{Dyno}	=	Moment of inertia of dynamometer rolls
Θ_{sim}	=	Additional simulated moment of inertia of dynamometer rolls
λ	=	Air number, air ratio
$\bar{\lambda}$	=	Mean air number
ρ	=	Gas density/Air density during standard conditions
ρ_I	=	Mass concentration of the component i/Density of the component i

Chapter I
Introduction

1.1 Statement of the Problem

The situation of air quality in Thailand during the year 1999 was slightly better in comparison to 1998. However, while ozone (O_3) levels rarely exceeded the standards, particulate matter (PM) was still a major problem. It was expected that air pollution might be reduced in the new millennium (21^{st} century) as a result of the continuous implementation of the strategy to control emissions from several point sources such as vehicles. Moreover, the continuing economic crisis has also affected the contributions of major air pollution point sources such as transportation.

In Bangkok Metropolitan Region (BMR), the suspended particulate matter remained the major air pollution problem, while O_3 and CO (8-hr. average) levels also significantly exceeded the standards. NO_X and SO_2 were below the standards. Due to the similarity of pollution from point sources in BMR and in vicinity with congested traffic areas, the major air pollution problem has been particulate matter. As for O_3, the value is usually slightly higher than the standards while the concentrations of CO, $NO_{X,}$ and SO_2 are, in general, below the standards.

In 1998, the total number of vehicles registered in the Bangkok Metropolitan Area was more than 3.8 million while the road space as a share of total area in Bangkok is only 11%, which is lower than the international standard of between the 20% and 25%. The number of vehicles has exceeded the road capacity. Thus, the more transport, the more fuel burned, which leads to a higher level of exhaust emissions released into the atmosphere.

Passenger cars are the largest number of the total vehicles registered in the Metropolitan Bangkok. The gases emitted from the exhaust pipes of these vehicles are carbon monoxide, hydrocarbons, nitrogen oxides, sulfur dioxide, and particulate matter. These pollutants have very harmful effects on the human health especially causing lung cancer. Exhaust emission test for gasoline and diesel engines is required by law. The standard of exhaust gases from the vehicle is defined by the regulation and legislation of Pollution Control Department in Thailand.

Thus, a study on reduction of exhaust emissions from the passenger cars using three-way catalytic converter could be very beneficial in combating air pollution problem of Bangkok area.

This study was conducted to investigate the reduction in exhaust emissions from some selected passenger cars by using the three-way-catalytic converter.

1.2 Research Objectives

Overall objective of this research was to investigate the reduction in exhaust emissions from the passenger cars by using three-way catalytic converter. Specific objectives of this study were as follows:

1.2.1 To determine a driving cycle for the suburban Bangkok Metropolitan Region (BMR) using some test passenger cars.

1.2.2 To measure and analyze the exhaust emissions from the test passenger cars equipped with and without catalytic converter during simulated driving cycles on a chassis dynamometer.

1.2.3 To estimate the existing and the future exhaust emissions from the passenger cars in Bangkok by using some mathematical model.

1.3 Scope and Limitations of the Study

1.3.1 Three passenger cars, manufactured by Mitsubishi Motor Corporation (MMC) equipped with and without three-way catalytic converter, were used in this study.

1.3.2 Driving cycles were obtained with the 3 test cars along the 3 selected traffic routes in suburban Bangkok Metropolitan Region.

1.3.3 Exhaust gas emissions were measured with the cars mounted on chassis dynamometer using the system installed at Mitsubishi Motor Corporation Sittipol Co. Ltd. in Prathumthani province of Thailand.

Chapter II

Significance of the Study and Literature Review

2.1 Origin of Automobile Exhaust Gas Emissions

Automobile exhaust gas emissions have their origin in the fuel combustion process in engine during which the chemical energy stored in various hydrocarbons is set free as oxidation heat. The basic physical processes taking place during the conversion of combustion heat in to mechanical work have been thoroughly experimentally researched and can be well described through suitable operating cycles. In comparison to this, the chemical processes in the combustion engine are relatively unknown (Klingkenberg, 1996; MMC,2001).

2.2 Chemistry of Engine Combustion

Air and gasoline are mixed in the engine carburetor to form a combustible mixture. This mixture is burned in the engine to produce power. Gasoline is made up largely of hydrogen and carbon and is called a hydrocarbon (HC). In the combustion process, the carbon and hydrogen in the gasoline unite with oxygen in the air. They form carbon dioxide (CO) and water (H_2O). If combustion were perfect, only carbon dioxide, water, and unused air would come out the tail pipe (Equation 2.1).

$$2HC + 2O_2 \rightarrow H_2O + 2CO_2 \tag{2.1}$$

Unfortunately, the combustion process is not perfect. Some of the carbon and oxygen end up as carbon monoxide which is formed as a result of burning gasoline with insufficient oxygen (Equation 2.2). A ratio of only 15 parts of CO to 10,000 parts of air is dangerous to breathe. Higher concentrations can be fatal.

$$3HC + 2O_2 \rightarrow H_2O + CO_2 + HC + CO \tag{2.2}$$

Since not all of the gasoline burns, some of it exits from the tail pipe as gasoline vapor (or HC). In addition to the CO_2, CO, H_2O, and HC coming out of the tail pipe, there are also oxides of nitrogen (NO_X).

At low temperatures, nitrogen is inert. It will not react chemically with anything, except under very special circumstances. High temperatures are required to form oxides of nitrogen. During the combustion process in the engine, temperatures above 3,500 °F (1,927 °C) are reached. At these high temperatures, some of the nitrogen in the air-fuel mixture reacts with oxygen to form oxides of nitrogen (Equation 2.3).

$$\text{HIGH TEMPERATURE} + \begin{Bmatrix} \text{OXYGEN(O)} \\ \text{AND} \\ \text{NITROGEN(N)} \end{Bmatrix} \rightarrow \text{NITROGEN OXIDES } (NO_X) \qquad (2.3)$$

These oxides of nitrogen react with hydrocarbons to produce smog as shown in Equation 2.4.

$$\text{SUNSHINE} + \begin{Bmatrix} \text{HYDROCARBONS} \\ \text{AND} \\ \text{OXIDES OF NITROGEN} \end{Bmatrix} \rightarrow \text{SMOG} \qquad (2.4)$$

Several different oxides of nitrogen may form during the combustion process in the engine. They vary in the amount of oxygen that reacts with the nitrogen. Some forms are highly toxic, meaning that they can be poisonous to breathe in excessive amounts (Crouse and Anglin, 1983).

The chemical process for the engine's energy conversion is the oxidation of fuel hydrocarbons with the oxygen of the admitted ambient air. The ideal transition is described as,

$$C_nH_{2n+2} + \frac{3n+1}{2}O_2 \rightarrow nCO_2 + (n+1)\,H_2O + \text{Heat} \qquad (2.5)$$

(Hydrocarbons + Oxygen) → (Carbon dioxide + Water + Heat)

Relating just to the C and H atoms of the molecules of the fuel, because of complex chemical composition, one can calculate how many kg of air needed on average for the complete combustion of 1 kg of gasoline.

The ratio of the actual air supply and the amount theoretically required is described as the air ratio l :

$$l = \frac{\text{amount of admitted air}}{\text{theoretical air demand}}$$

$l = 1$ for stoichiometrical relationship

$l < 1$ for lower amount of air

$l > 1$ for rich mixture and with excess air

The mass balance of the complete fuel combustion in gasoline, that is ideal, ($\overline{l}$ is the mean air ratio) is as follows :

Gasoline Engine (Assumption $\overline{l} = 1$) :

$$1 \text{ kg fuel } (\cong C_{6.2} H_{2.6} O_{1.1}) + 14.9 \text{ kg air } (\cong 3.4 \text{ kg } O_2 + 11.5 \text{ kg } N_2) \rightarrow 3.1 \text{ kg } CO_2 + 1.3 \text{ kg } H_2O + 11.5 \text{kg } N_2 \quad (2.6)$$

Carbon dioxide and hydrogen are the oxidation products and the proportion of nitrogen remains unchanged (Klingenberg, 1996).

2.2.1 Typical Composition of Automobile Exhaust Gas

Complete fuel combustion producing just carbon dioxide and water is not practicable even with a very lean mixture. This is due to the fact that in the combustion phase of the engine's operating cycle, the chemical reactions reach no equilibrium conditions and non-homogeneous gas mixtures appear, making secondary chemical reactions possible (incomplete combustion).

Observed values of the exhaust emission components of a typical gasoline engine vehicle without catalytic converter are listed in Table 2.1. The table could be continued for hundreds of exhaust gas components with progressively lower concentrations.

Over 98% by weight of the exhaust gas is made up of carbon dioxide, water, oxygen, nitrogen and hydrogen. These are followed by limited exhaust components as characteristic products of incomplete combustion with a total of about 1.6% by weight. These are carbon monoxide - an intermediate stage of carbon dioxide formation, then total hydrocarbons - the unburned and cracked fuel components along with their newly formed chemical compounds, and finally, nitrogen oxides (NO_X)- oxidation products of the intake air nitrogen mainly nitrogen monoxide (NO) and nitrogen dioxide (NO_2).

2.2.2 Conversion of Mass Concentrations to Volume Concentrations

The emission concentration of the component, *i* is normally given either as mass concentration (Klingenberg, 1996):

$$\boldsymbol{r}_i = \frac{m_i}{V_{total}} \quad (2.7)$$

where,

m_i = mass of component *i* in mg

V_{total} = total volume of the gas probe in m^3

ρ_i = mass concentration in mg/m^3

Table 2.1 Typical composition of gasoline engine exhaust gas.

Component	Formula	kg/kg fuel	kg / 1 fuel	Weight %	Vol. %
Carbon dioxide	CO_2	2.710	2.019	17.0	10.9
Water vapor	H_2O	1.330	0.990	8.3	13.1
Oxygen	O_2	0.175	0.130	1.1	1.0
Nitrogen	N_2	11.500	8.586	72.0	72.8
Hydrogen	H_2	$5.6x10^{-3}$	$4.2x10^{-3}$	$3.5x10^{-2}$	0.5
Sum				**98.4**	**97.8**
Carbon monoxide	CO	0.224	0.167	1.4	1.4
Hydrocarbons	HC	$2.0x10^{-2}$	$1.5x10^{-2}$	0.13	0.27
Nitrogen oxide	NO_X	$1.7x10^{-2}$	$1.3x10^{-2}$	0.11	0.1
Sum				**1.64**	**1.77**
Sulfur dioxide	SO_2	$3.5x10^{-4}$	$2.4x10^{-4}$	$2.0x10^{-3}$	$9.0x10^{-4}$
Sulfates	SO_4^{2-}	$2.3x10^{-5}$	$1.7x10^{-5}$	$1.5x10^{-4}$	$4.0x10^{-5}$
Aldehydes	RCHO	$3.4x10^{-4}$	$2.5x10^{-4}$	$2.0x10^{-3}$	$2.0x10^{-3}$
Ammonia	NH_3	$1.5x10^{-5}$	$1.1x10^{-5}$	$1.0x10^{-4}$	$1.5x10^{-4}$
Lead compounds	-	$1.0x10^{-4}$	$7.5x10^{-5}$	$6.0x10^{-5}$	-

Note From Automobile Exhaust Emission Testing, Klingenberg, 1996, Germany : Springer

or as volume concentration:

$$s_i = \frac{V_i}{V_{total}} \qquad (2.8)$$

where,

V_i = volume proportion of the component *i* in ml

The following ratio is valid for gases:

$$\frac{s_i}{r_i} = \frac{V_i}{m_i} = \frac{V_m}{M_{mi}} \qquad (2.9)$$

where,

s_i = volume concentration in ml/m^3 (ppm)

r_i = mass concentration in mg/m^3

V_m = molar volume in m^3/kmol

M_{mi} = molar mass of the component *i* in kg/kmol (10^6 kg / kmol)

The following equations result for the calculation of mass concentrations (mg/m^3) in volume concentrations (ppm) and vice versa:

$$\mathbf{s}_i \text{ in ppm} = \frac{V_m}{M_{mi}} \mathbf{r}_i \,(\mathbf{r}_i \text{ in mg/m}^3) \qquad (2.10)$$

and

$$\mathbf{r}_i \text{ in mg/m}^3 = \frac{M_{mi}}{V_m} \mathbf{s}_i \,(\mathbf{s}_i \text{ in ppm}) \qquad (2.11)$$

Right hand side of these equations are nondimensional. The factor 10^{-6} is implicitly included by the calculation of mg to kg.

The molar volume for ideal gases in the ambient conditions of p_a = 1.013×10^5 Pa and T_a = 293° K (20°C) is calculated from the ideal gas equation to:

$$V_m = \frac{R_m T_a}{p_a} = 24.36 \text{ m}^3\text{/kmol} \qquad (2.12)$$

where,

R_m = molar gas constant (8,314.5 Pa m^3/kmol K)

T_a = ambient temperature in ° K

p_a = atmospheric pressure in Pa

For the determination of molar mass, the atomic masses from the periodic table can be used if accuracy permits.

For example:

$$M_{mCO} = 12 + 16 = 28 \text{ kg/kmol} \qquad (2.13)$$

The molar masses and calculation factors for few important gases are given in Table 2.2.

Table 2.2 Molar masses and calculation factors of selected gases in an ambient condition of 20 °C and 1.013×10^5 Pa.

Component	Formula	M_{mi} in kg/kmol	(V_m/M_{mi}) in ppm/mg m^{-3}	(M_{mi} / V_m) in mgm^{-3} / ppm
Carbon monoxide	CO	28	0.870	1.149
Hydrocarbons	HC	-	-	-
Carbon dioxide	CO_2	44	0.554	1.806
Nitrogen monoxide	NO	30	0.812	1.231
Nitrogen dioxide	NO_2	46	0.530	1.888
Ozone	O_3	48	0.508	1.970

Note From Automobile Exhaust Emission Testing, Klingenberg, 1996, Germany : Springer

2.3 Hydrocarbon Emission Sources of a Motor Vehicle

Studies of the automobiles indicated that they gave off pollutants from four sources (Figure 2.1). These are the crankcase, the carburetor, the fuel tank, and the exhaust system. When hearing the words "Emission sources of a motor vehicle" most think merely of the exhaust emission from the exhaust pipe. Frequently, the hydrocarbon (HC) evaporation emissions are forgotten. Evaporation and fueling emissions form part of the hydrocarbon pollution of the air by motor vehicles.

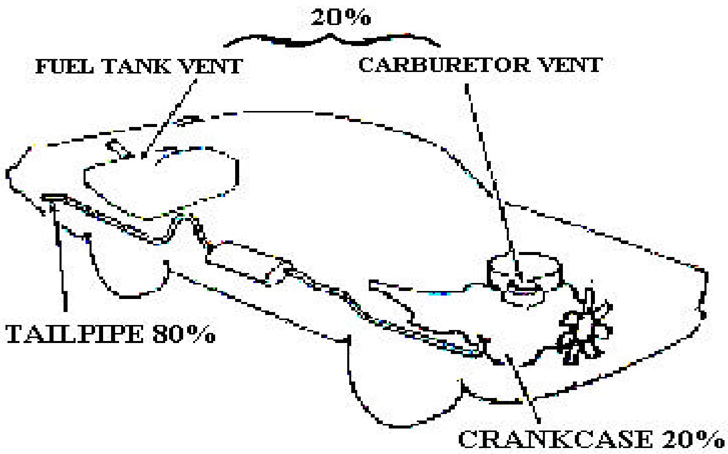

Figure 2.1 The sources and percentages of atmospheric pollution from automobiles (Source: Crouse and Anglin, 1983)

2.3.1 Evaporation Emissions

Evaporation is defined as the release of gaseous and vaporous hydrocarbons into the environment by evaporation from various parts of the vehicle. (The HC emissions from the crankcase and the engine are not included here.)

The evaporation emissions also include all volatile hydrocarbon compounds from the parts and materials utilized in the manufacture or the use of the vehicle. These are, for example, solvents and thinners for paint, glue and sealing compounds, foam material, underbody coating, and preservation compounds and their pyrolysis products.

Furthermore, the fuel also evaporates from the technically required openings of the fuel system and diffuses through the walls of the container and pipes into the outsides air.

These evaporation losses are characterized by a HC vapor release from various parts of a vehicle distributed over a along period of a time. A maximum of 0.4g/min vaporizes from the fuel system. The amount emitted is responsible for a yearly average of 7.4g HC per day per vehicle as shown in Figure 2.2.

2.3.2 Fueling Emissions

Fueling emissions are defined as gaseous and vaporous hydrocarbons escaping from the fuel tank during fueling due to the displacement of the gas (fuel vapor and air) in the tank. It is characterized by an emission of HC vapors concentrated over a period of a few minutes from a limited source, the filler neck. A maximum of 80 g/min is emitted in this way (Klingenberg, 1996).

When filling the fuel tank, the air laden with fuel vapors to varying degrees is displaced from the tank into the open as shown in Figure 2.3. The hydrocarbon amounts fluctuate depending on ambient conditions, fuel quality, filling rate, internal tank design, and the fueling nozzle as well as the way in which the nozzle is introduced into the tank.

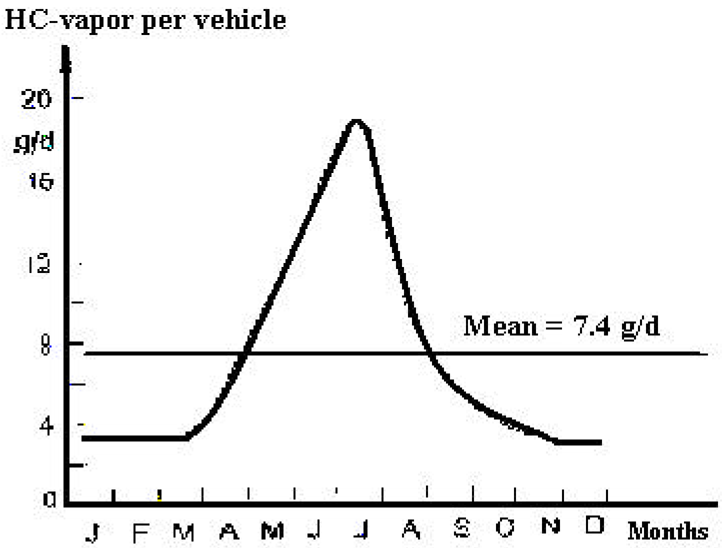

Figure 2.2 Vapor emissions from the fuel system per vehicle over one year (Source: Crouse and Anglin, 1983)

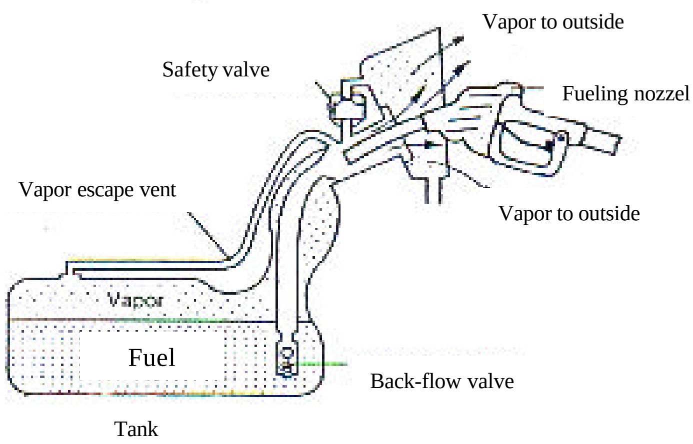

Figure 2.3 Fueling emissions (Source: Crouse and Anglin, 1983)

The vapor contains approximately 1 g of hydrocarbons per liter of fuel under normal fuel vapor pressure (of 6×10^4 Pa acc. To Reid), at a filling rate of 30 L/min and a fuel and tank temperature of below 15 ^{o}C. On the average 50 g are emitted per fueling, annually around 1,000 g per vehicle with 10,000 km driven per year on an average. The amount of hydrocarbons clearly rises with the filling rate and the temperature (Klingenberg, 1996).

2.4 Three basic regulated pollutants in vehicle emission

Legal limits have been set for three basic pollutants from engines : unburned gasoline (HC), carbon monoxide (CO), and nitrogen oxide (NO_X). Some HC vapor also escapes from the carburetor and fuel tank in a car without emission controls. HC is highly volatile and evaporates very easily. It must be made to evaporate easily to produce the air-fuel mixture needed to run the engine. The space above the gasoline in the fuel tank is filled with gasoline vapor. On a car without emission controls, some of the gasoline vapor passes out through the vent in the tank or cap. A small reservoir of gasoline is stored in the carburetor. Some of this gasoline also evaporates after the engine has been turned off. So the carburetor and fuel tank are other sources of gasoline vapor, in addition to the engine.

If the car is in poor condition, needing an engine tune-up, with fouled spark plugs that do not fire consistently, and an out-off-adjustment carburetor, the amount of pollutants goes up. The car can give off two or three times as much pollutants as another car in good condition.

Hydrocarbons (HC)

Hydrocarbons are the result of incomplete combustion. That is, hydrocarbon emissions are excesses of fuel that have been left unburned, or partially burned, in the combustion chamber after ignition has occurred. In principal, the lower the HC, the better the engine is running. Excessive hydrocarbons indicate that either the engine is misfiring, due to an internal problem or the carburetion is not balanced (mixtures that are too rich, or to lean.) A lean mixture will cause a lean misfire, which of course, raises hydrocarbon levels.

Carbon monoxide (CO)

Carbon monoxide is the result of incomplete combustion of the fuel due to an insufficient amount of oxygen in the air/fuel mixture. In principal, the lower the CO reading as indicated by an infrared analyzer, the leaner the carburetion mixture going into the engine. In other words, CO reading is a direct indication of the mixture.

Of course, other factors can also affect the carbon monoxide emission level of an engine. Anything that restricts air flow to the combustion chamber of the engine; such as: dirty air filter elements, restricted air bleeds in the carburetor, blockage in the intake manifold, or cylinder heads, etc., can cause high CO emission levels.

Oxides of nitrogen (NO_X)

Oxides of nitrogen are generated when combustion temperatures reach high levels. Since the earth's atmosphere consists of a larger percentage of nitrogen than any other element, the combustion chamber of the engine see more molecules of nitrogen.

The chemical nature of nitrogen and oxygen require very high temperatures in order to combine both elements in any form. The "X" in NO means that an oxide of nitrogen is formed when one molecule of nitrogen combines with any number of molecules of oxygen (NO, NO_2, NO_3, etc.). Ninety five percent or more is NO in the engine's exhaust.

In principal, the higher the temperature and pressure of combustion, the higher NO levels contained in the engines exhaust (MMC, 1990).

2.5 Controlling Automobile Pollution Sources

In the modern automobile, each pollution source is controlled by separate emission control systems. For example, the amount of air pollutants that escape from the engine crankcase is now controlled by the crankcase emission control system. Exhaust emissions are controlled by a variety of systems and devices. The air- injection reactor (AIR), or air pump, was one of the first devices widely used to control hydrocarbons and carbon monoxide in the engine exhaust gas. Another early approach to controlling exhaust emissions was the engine modifications, or controlled-combustion system (CCS). It combined several engine modifications and calibrations. This system did not use an air pump.

To control the amounts of nitrogen oxides that form in the engine during the combustion process, engines are equipped with an exhaust-gas recirculation (EGR) system. A small amount of exhaust is returned to the intake manifold, so that air-fuel mixture burns at a lower temperature. This reduces the formation of nitrogen oxides (NO_X). To further reduce exhaust emissions, most new cars have a catalytic converter as shown in Figure 2.4. Fuel evaporation from the carburetor and fuel tank is controlled by the evaporative control system.

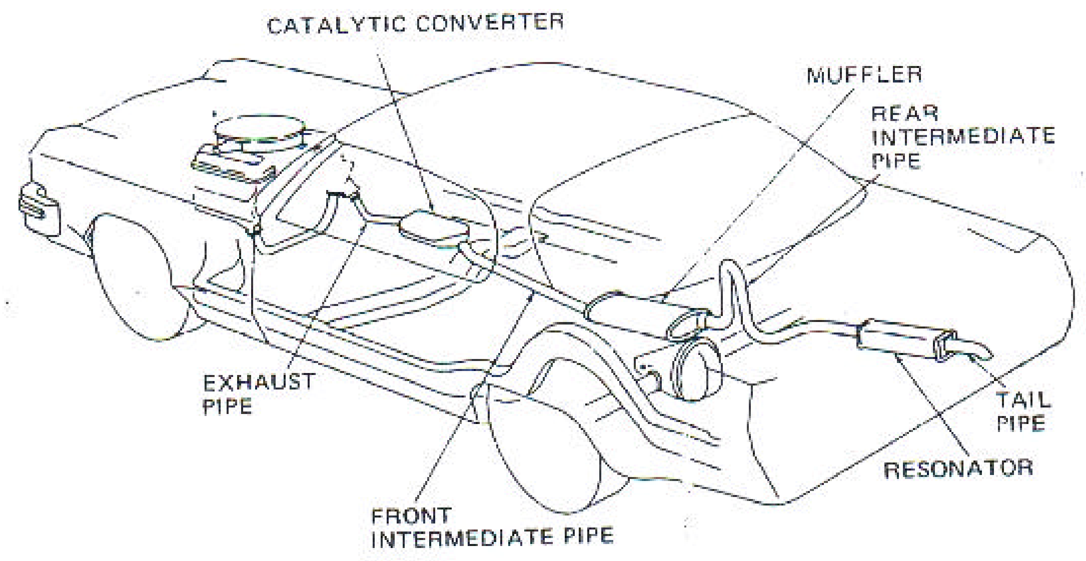

Figure 2.4 Location of the catalytic converter in the exhaust system of a car (Source: Crouse and Anglin, 1983)

2.5.1 Exhaust Emission Control

Exhaust emissions (Carbon Monoxide, Hydrocarbons, and Oxides of Nitrogen) are controlled by a combination of engine modifications and the addition of special control components. Modifications are applied to the combustion chamber, intake manifold, camshaft, carburetor and heated air intake system.

Additional engine control devices include an Exhaust Gas Recirculation System (EGR) to reduce oxides of nitrogen emissions, FBC or ECI-Multi system, secondary air supply system, and catalytic converter. These devices have been integrated into a highly effective system, which controls exhaust emissions while maintaining good vehicle performance.

2.5.2 Crankcase Emission Control

A closed-type crankcase ventilation system is utilized to prevent the blow-by gas from escaping into the atmosphere. This system has a positive crankcase vent valve (PCV valve). All automobile engines now built are equipped with the positive crankcase ventilation system of crankcase emission control. In this system, fresh air flows through the crankcase and mixes with the crankcase fumes. From the crankcase, the fumes and air travel to the intake manifold. There, the fumes are mixed with the fresh incoming air-fuel charge. Then the mixture enters the engine cylinders. This gives the previously unburned gasoline contained in the blowby another chance to burn. Without this system, the unburned fuel in the blowby escapes into the atmosphere and is wasted.

2.5.3 Evaporative Emission Control

In order to prevent the loss of fuel vapor from the fuel system into the atmosphere; the evaporative emission control system consists of charcoal canister, a bowl vent valve, a purge control valve, etc. is adopted.

2.6 Cleaning the Exhaust Gas

Exhaust emissions may be reduced by controlling the air-fuel mixture, controlling the combustion process, and treating the exhaust gas. In order to meet today's emission standards, most engines must use all three methods. These various combinations are required to limit the amounts of HC, CO, and NO_X in the exhaust gas. Treatment of the exhaust gas means that some "cleaning" action must occur after the exhaust gases leave he engine cylinders and before they exit the tail pipe and enter the atmosphere. Two methods are widely used. These are the air-injection system and the catalytic converter.

2.6.1 Catalytic reactions for Automobile Pollution Control

Catalytic converters provide another way to treat the exhaust gas (Figure 2.5). These devices, located in the exhaust system, convert harmful pollutants into harmless gasses. Inside the catalytic converter, the exhaust gases pass over a large surface area coated with a catalyst. A catalyst is a material that causes a chemical reaction without actually becoming a part of the reaction process. For example, the metals platinum and palladium can act as an oxidizing catalyst.

When exhaust gas and air are passed through a bed of platinum- or platinum-coated pellets, or through a coated honeycomb core, the HC and CO react with the oxygen in the air (O_2). Harmless water (H_2O) and carbon dioxide (CO_2) are formed (Figure 2-6). When the metal rhodium is used, the nitrogen oxides (NO_X) in the exhaust gas are reduced to harmless nitrogen (N_2) and oxygen (O_2). Therefore, rhodium is known as a reducing catalyst.

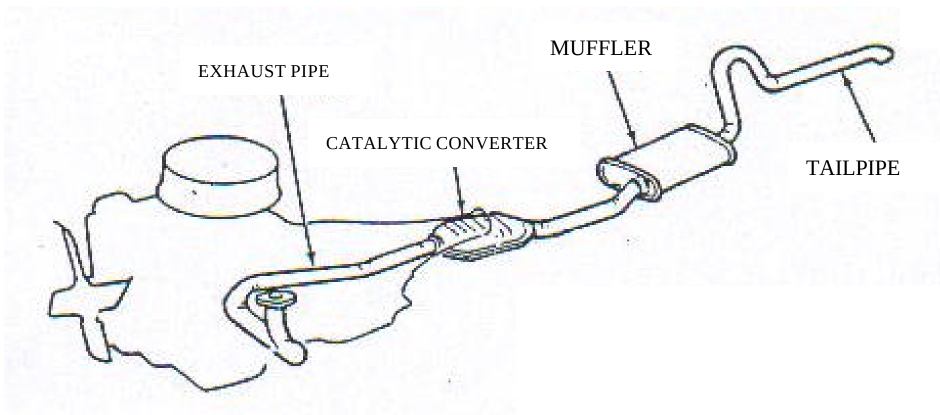

Figure 2.5 Catalytic converter removes pollutants from gas flowing through exhaust system (Source: Crouse and Anglin, 1983)

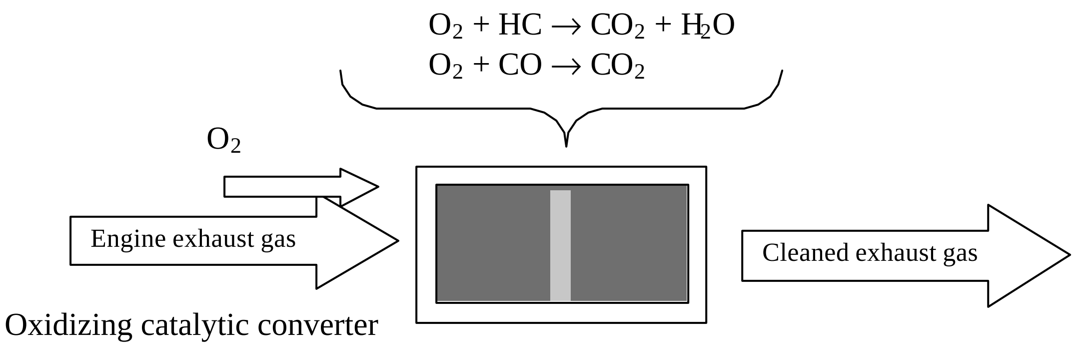

Figure 2.6 Action of the catalytic converter (Source: Crouse and Anglin, 1983)

2.6.2 Types of Catalytic Converters

There are three types of catalysts for automobile use. They are: the oxidation catalyst, reduction catalyst, and three-way catalyst. The oxidation catalyst accelerates oxidation of CO and HC. The reduction catalyst accelerates reduction of NO. The three-way catalyst accelerates both oxidation and reduction simultaneously at an equilibrium point of gas contents (theoretical air-fuel ratio).

Structurally, two types of catalysts are used: **Pellet** type and **Monolith** type. MMC formerly used the pellet type catalyst. Lately, the monolith type, one of alumina honeycomb structure, has been used. The monolith type has the following features:

(1) High catalytic activity per volume.

(2) Small heat capacity. Quick start of catalytic action after engine start in cold weather. (Good warming up characteristic)

(3) High gas permeability per unit are of cross-section of passage.

(4) Because of monolith structure, the construction of converter is made simple. (MMC, 1990)

Figure 2.7 shows a two-way pellet- or bead-type catalytic converter. It acts on the exhaust gas two ways, converting HC and CO to carbon dioxide and water. The converter is filled with coated pellets about the size of BB shot. As the exhaust gas flows through, the catalyst coating the pellets produces the chemical reaction. Another type of two-way catalytic converter construction has a catalyst-coated honeycomb through which the exhaust gas must pass (Figure 2.8). This is called a monolith-type catalytic converter.

Both types of two-way catalytic converters require additional air in the exhaust gas. Therefore, the engines will be equipped with either the air injection system or the air-aspirator system. Cars equipped with catalytic converters must use nonleaded gasoline. If the gasoline contains lead, the lead will coat the catalyst and the converter will stop working. If this happens to the pallet- type converter pallets can be replaced. The catalytic converter would be in high temperature. Therefore, the floorpan above it must be insulated to prevent this heat from flowing up into the passenger compartment.

Some engines have a mini-converter in addition to the main catalytic converter (Figure 2.9). The miniconverter is located close to the exhaust gas manifold. This enables the miniconverter to heat up quickly, thereby reducing HC and CO emissions during engine warm-up.

The dual-bed converter is like two-bead type converters in one housing with an air chamber between them. The exhaust gas first passes through the upper bed, reducing the NO_X and oxidizing some of the HC and CO. Then the exhaust gas flows through the air chamber to the lower bed, where the air pump is adding sufficient air for final oxidizing of the HC and CO.

A three-way catalyst is a mixture of platinum and rhodium (sometimes mixed with palladium). It acts on all three of the regulated pollutants (HC, CO, and NO_X), but only when the air-fuel-mixture ratio is precisely controlled.

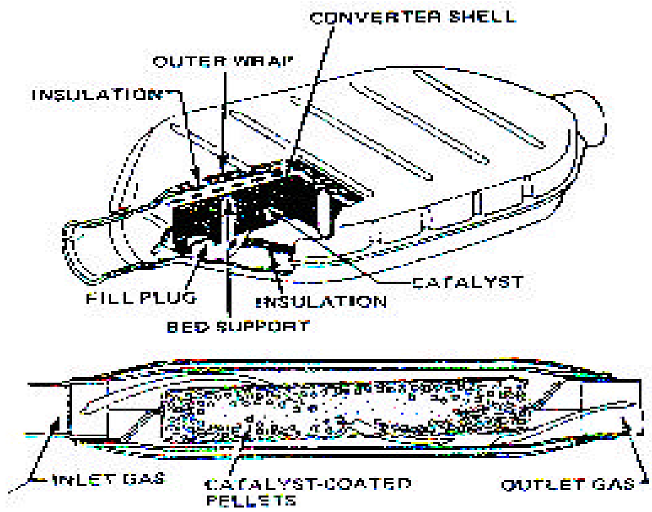

Figure 2.7 Sectional view of a two-way pellet, or bead, type of oxidizing catalytic Converter (Source: Crouse and Anglin, 1983)

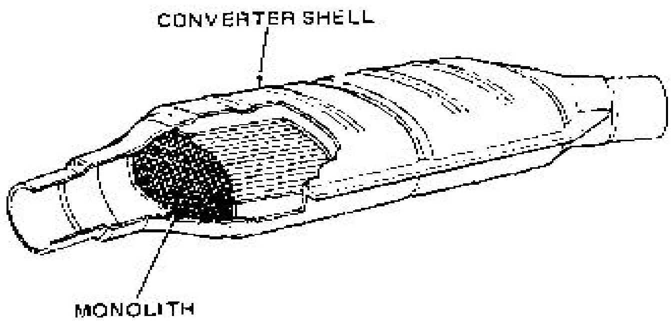

Figure 2.8 Construction of monolyth type of two-way catalytic converter. (Source: Crouse and Anglin, 1983)

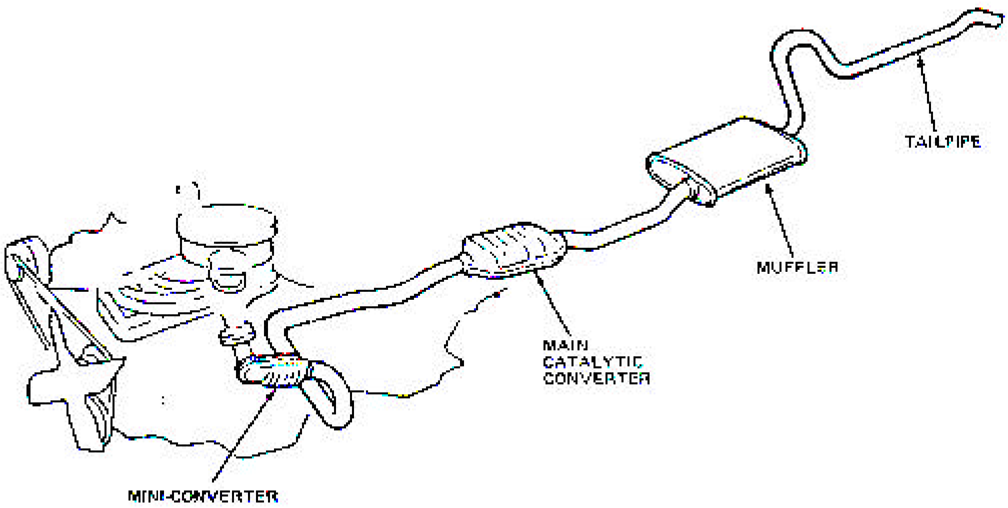

Figure 2.9 Exhaust system using a miniconverter ahead of the main catalytic converter. (Source: Crouse and Anglin, 1983)

Dual-bed and three-way converters

If the engine is operated with the ideal or stoichiometric air-fuel ratio of 14.7:1, the three-way catalyst is very effective. It strips oxygen away from the NO_X to form harmless water, carbon dioxide, and nitrogen gas. However, the air-fuel mixture must be precisely controlled if this action is to occur. For this reason, a closed-loop fuel-metering system or fuel injection must be used. Otherwise, the three-way catalyst does not work.

Figures 2.10 and 2.11 show two types of three-way catalytic converters. They have a mesh or honey comb coated with catalyst. The front section (in the direction of gas flow) handles NO_X and partly handles HC and CO. The partly treated exhaust gas then flows through the air chamber into the rear section of the converter, where the gas mixes with the air being pumped in by the air pump. This is called secondary air. It puts more oxygen in the exhaust gas so that the two-way catalyst can take care of the HC and CO. The air pump sends air into the converter only when the engine is at normal operating temperature. When the engine is cold, the air from the air pump goes into the exhaust manifold.

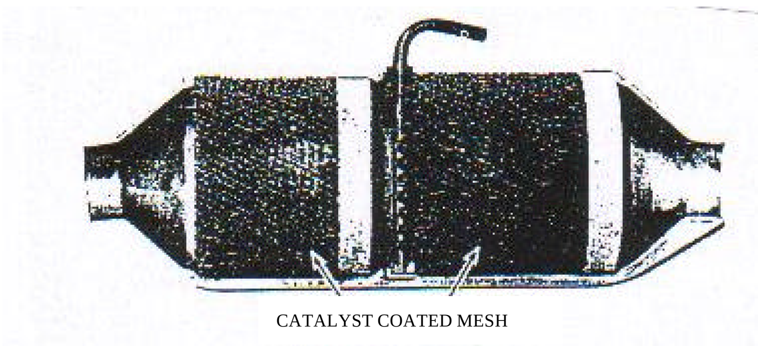

Figure 2.10 A three-way catalytic converter using a mesh coated with catalyst. (Source: Crouse and Anglin, 1983)

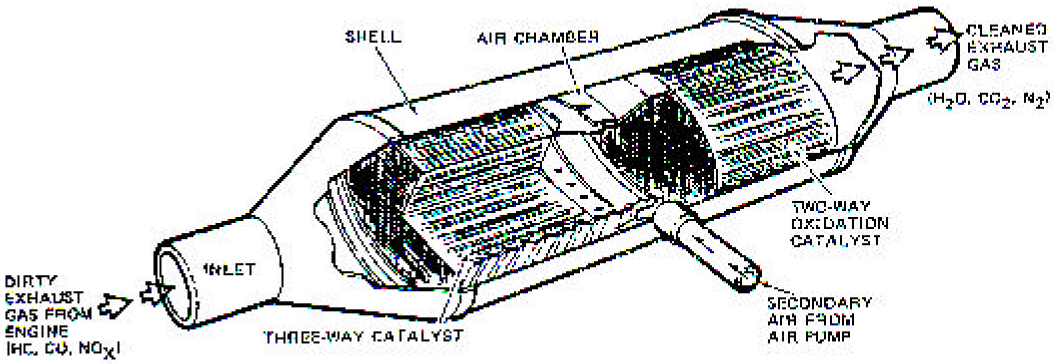

Figure 2.11 A three-way catalytic converter using a monolith, or honeycomb, coated with catalyst (Source: Crouse and Anglin, 1983)

2.6.3 Function of A Catalytic Converter

In catalytic converter, HC, CO and NO_X are changed into harmless CO_2, H_2O, N_2 and O_2. As the catalytic reaction takes place, normal internal temperature of the catalytic converter rises to somewhat between 400 to 700 °C (750 to 1300 °F), while normal outer surface heat generally reaches around 150 to 300°C (300 to 570 °F).

However, if the engine is in poor operating condition, is operating under a severe load, is in need of a tune-up, or has several misfiring cylinders, higher temperatures than normal are easily reached, both inside and outside the converter shell. Excessively high temperatures reduce converter life and can destroy the cores.

This situation can also occur during diagnostic testing if any spark plug cables are removed and the engine is allowed to idle for a prolonged period of time.

2.6.4 The Saturn 3-Way Catalytic Converter

This three-way converter is an emission control device added to the exhaust system to reduce pollutants from the exhaust gas stream and requires the use of unleaded fuel only. The coating on the three-way converter contains platinum and rhodium which lowers the levels of oxides of nitrogen (NO_X) as well as hydrocarbons (HC) and carbon monoxide (CO) (Figure 2.12).

Figure 2.12 The Saturn 3-way Catalytic Converter (LowSC2 Tech Center) (Source: http://www.lowsl2.com/cat_con.html)

To reduce HC, CO and NO_X emissions, they are oxidized, reduced and converted to nitrogen (N_2), carbon dioxide (CO_2) and water (H_2O) by the catalyst as shown in Table 2.3.

Table 2.3 Action of the three-way catalytic converter

Exhaust Port		Three Way Converter		Exhaust Gas
HC CO NO_X	→	Oxidation and Reduction	→	CO_2 H_2O N_2

Note From http://www.lowsl2.com/cat_con.html

2.7 Standards and Guidelines for Ambient Air Pollutants' Concentrations

U.S.EPA. standards are widely used for developing local standards. Table 2.4 shows the comparison of ambient air quality standards in some countries. Table 2.5 shows the Ambient Air Quality Standards for Thailand set up in 1995, which were also developed by following the U.S.EPA. standards.

2.8 Emission Standards for Automobiles

Early analysis of the automobiles with no emission controls shows the sources of emissions to be as follows :

Table 2.4 Emission Standards for Automobiles

Source	Pollutant %			
	CO	HC	NO_X	Particles
Exhaust	100	62	100	90
Crankcase emission		20		10
Fuel tank evaporation		9		
Carburetor evaporation		9		

As an additional complication, the mode of vehicle operation has marked effect upon its emissions. In 1960, the Motor Vehicle Pollution Control Board of the State of California was created in USA to establish specifications on vehicle exhaust and evaporative emissions. The first automotive emission requirement was for the reduction of crankcase blow-by. The board adopted a resolution requiring that a positive crankcase ventilation system be installed on all new cars sold in California beginning with the 1963 models. The federal government, by an amendment to the Clean Air Act of 1965, specifically authorized the writing of the national emission standards for all motor vehicles sold in the United States. The program has since become known as the Federal Motor Vehicle Control Program (FMVCP). Emission standards have been established under the FMVCP and other programs for a wide variety of mobile sources including automobiles, trucks, buses, aircraft, and other non-road mobile sources. Table 2.6 summarizes the progressive stringency of emission standards for the two most common types of vehicles, referred to as light duty vehicles (LDV) and light duty trucks (LDT). LDT includes light duty truck rated up through 600 lbs. gross vehicle weight rating (GVWR). The emission standards are expressed in grams/mile and are based on a federal test procedure refer to as FTP-75, which measures the weighted emissions associated with a specific cycle of operating modes. (Rammont, 1999)

Table 2.5 : Comparison of Ambient Air Quality Standards in Some Countries

Country	SO_2			NO_2			CO		O_3		TSP		PM_{10}		Pb		
	1 hr	24 hrs	Annual	1 hr	24 hrs	Annual	1 hr	8 hrs	1 hr	8 hrs	24 hrs	Annual	24 hrs	Annual	1 hr	24 hrs	Annual
USA	-	0.37	-	-	-	0.10	40.0	10.0	0.24	-	-	-	0.15	0.05	-	-	-
Japan	0.26	0.11	-	-	0.08	-	-	22.8	0.12	-	-	-	-	-	0.10	-	-
Netherlands	0.76	0.23	-	0.18	-	-	40.0	6.0	0.12	-	-	-	-	-	2.00	-	-
Australia	0.44	0.16	-	0.30	0.12	-	34.3	11.4	0.24	0.10	-	-	-	-	-	-	-
Mexico	-	-	-	0.40	-	-	-	15.0	-	-	-	-	-	-	-	-	-
Taiwan	0.78	0.26	-	-	0.10	-	22.9	-	-	-	-	-	-	-	-	-	-
Canada	0.82	0.27	-	0.40	0.20	-	15.0	6.0	0.10	-	-	-	-	-	-	-	-
Germany	-	0.27	-	0.20	-	0.80	30.0	-	-	-	-	-	-	-	-	-	2.00
WHO	0.35	0.13	0.05	0.40	0.15	-	30.0	10.0	0.15	0.10	-	-	-	-	-	-	0.50
Thailand	0.78	0.30	0.04	0.32	-	-	34.2	10.3	0.20	-	0.33	0.10	0.12	0.05	-	1.50	-

Note From PCD, 2001

Table 2.6 Ambient Air Quality Standards in Thailand, 1995

Pollutants	1- hr average		8 – hr average		24 - hr average		1- month average		1 - year average**		Methods
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	
1. Carbonmonoxide (CO)	34.2	30	10.26	9	-	-	-	-	-	-	Non - Dispersive Infrared Detection
2. Nitrogen Dioxide (NO_2)	0.32	0.17	-	-	-	-	-	-	-	-	Chemiluminescence
3. Sulfur Dioxide/ [a] (SO_2)	0.78	0.3	-	-	0.3	0.12	-	-	0.10*	0.04	UV - Fluorescence
4. Total Suspended Solid (TSP)	-	-	-	-	0.33	-	-	-	0.10*	-	Gravimetric - High Volume
5. Particulate Matter (< 10 µ)(PM_{10})	-	-	-	-	0.12	-	-	-	0.05*	-	Gravimetric - High Volume
6. Ozone (O_3)	0.2	0.1	-	-	-	-	-	-	-	-	Chemiluminescence
7. Lead (Pb)	-	-	-	-	-	-	1.5	-	-	-	Atomic Absorbtion Spectrometer

Remark : * At 1 standard pressure and 25 ^{O}C ** geometric mean

/a • 1- hr SO_2 Standard: 1.3 milligram/cubic meter for Mae Moh area and 0.78 milligram/cubic meter, elsewhere

Note From Pollution Control Department (1995)

Table 2.7 US Federal Vehicle Emission Standards

Year	Light Duty Vehicles (auto)				Light Duty Trucks			
	HC (g/mi)	CO (g/mi)	NO_X (g/mi)	PM (g/mi)	HC (g/mi)	CO (g/mi)	NO_X (g/mi)	PM (g/mi)
1968	3.2	33						
1971[*]	4.6	47	4.0					
1974	3.4	39	3.0					
1977	1.5	15	2.0					
1978	1.5	15	2.0		2.0	20	3.1	
1979	1.5	15	2.0		1.7	18	2.3	
1980	0.41	7.0	2.0		1.7	18	2.3	
1981	0.41	3.4	1.0		1.7	18	2.3	
1982	0.41	3.4	1.0	0.6[a]	1.7	18	2.3	
1985	0.41	3.4	1.0	0.6[a]	0.8	10	2.3	1.6[a]
1987	0.41	3.4	1.0	0.2[a]	0.8	10	2.3	2.6[a,b] 0.5[a,c]
1988	0.41	3.4	1.0	0.2[a]	0.8	10	1.2[b] 1.7[c] 2.3[d]	0.26[a,b] 0.45[a,c]
1990	0.41	3.4	1.0	0.2[a]	0.8	10	1.2[b] 1.7[c]	0.26[a,b] 0.45[a,c]
1991	0.41	3.4	1.0	0.2[a]	0.8	10	1.2[b] 1.7[c]	0.26[a,b] 0.13[a,c]
Tier 1 Intermediate Useful Life Standards (g/mi)								
1994	0.41[a,c] 0.25[a,e,f] 0.041[g,i] 0.25[g,h]	3.4	0.4[e,g] 1.0[a]	0.08	0.25[a,b,e,f] 0.25[b,g,h] 0.32[a,c,e,f] 0.32[c,g,h]	3.4[b] 4.4[c]	0.4[b,e,g] 0.7[c,e,g] 1.0[a,b]	0.08
Tier 1 Full Life Standards (g/mi)								
1994	0.31[a,e,f] 0.31[g,h]	4.2 4.2	0.6[e,g] 1.25[a]	0.10	0.8[a,b,c,e] 0.8[g,I] 0.31[a,b,e,f] 0.31[b,g,h] 0.40[a,c,e,f] 0.40[c,g,h]	4.2[b] 5.5[c]	0.6[a,b,e,f] 0.97[c] 1.25[a,b]	0.10

[a]Diesel [b]LVW < 3750 lbs [c]LVW > 375 lbs [d]LVW > 6001 lbs

[e]Gasoline [f]Non-methane Hydrocarbons [g]Methanol

[h]Org.Mat. Non-methane HC Equivalent [I]Org.Mat HC

[*]Test method changed in 1971

Note : Wark et al, 1998

2.9 Air Quality in Bangkok

Despite measures being undertaken to improve the situation in Bangkok, monitoring of the air pollutants by the Pollution Control Department (PCD) showed that the deteriorating air quality remains a problem. Air pollution has been monitored by the PCD since 1984 by measuring the concentrations of carbon monoxide (CO), total suspended particulates (TSP), lead (Pb), and their variance from the standards set by the Office of the National Environment Board (ONEB) (Rammont, 1999).

In 1997, the Pollution Control Department (PCD) continuously recorded the air quality data through the monitoring stations. From these measurements in Bangkok, it was found that the most significant problem was still dust, but the values were lower than the previous year. While other pollutants such as ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, were high at some monitoring stations, lead levels were far below the ambient air quality standard and were significantly reduced from 1991, when lead free gasoline was introduced (Rammont, 1999).

Particulate Matter (PM_{10})

Small suspended particulate matter (PM_{10}) can enter the inner lungs. The highest 24-hour average value was 305 $\mu g/m^3$ (at Singharaj Pithayakom School, Bang Khunthien) which is 2.5 times higher than standard (120 $\mu g/m^3$).

Total Suspended Particulate Matter; TSP

The highest 24-hour average TSP values was 0.51 mg/m^3 at Singharag Pithayakom school, Bang Khunthien, which is 1.5 times higher than standard (0.33 mg/m^3). By comparing TSP values in 1997 to previous year; it was found that the annual average trends was lower.

Carbon monoxide; CO

Most of an hourly average CO values were lower than standard (30 ppm) except at Department of Meteorology (Bangna) which was found to be the highest at 36.6 ppm.

Nitrogen dioxide; NO_2

Most of an-hourly average NO_2 were below the standard value of 170 ppb, except at Rajabhat Bansomdej Institute and Nontri Vidhaya School, which had the highest values of 188 and 172 ppb, respectively.

Sulphur dioxide; SO_2

The hourly average SO_2 values at all stations were below the standard value of 300 ppb. The highest value was 186 ppb.

Lead; Pb

The hourly average lead values at all stations were below the standard value of 1.5 $\mu g/m^3$. The highest value was 0.79 $\mu g/m^3$.

Ozone; O_3

The highest hourly average O_3 value was 423 ppb, which is 4.2 times higher than standard (100 ppb). The number of highest O_3 concentrations were more than the previous year for all stations.

2.10 Government Measures to Combat Vehicular Air Pollution in Thailand

The public and the government are voicing serious concern about the increasing trend of air pollution problem, particularly in the Bangkok Metropolitan Region. An effort is being made by the government to restore the quality of the air, in cooperation with industry, the public, and Non-Government Organizations (NGOs). Measures to mitigate air pollution problems, particularly those caused by the transport sector, are aimed not only at exhaust gas emission controls but also at improvement of the fuel and vehicles specifications, implementation of in-use vehicle inspection and maintenance program, public transport improvement through mass transit system, and the improvement of traffic conditions through better traffic management. Some other measures directed towards reducing vehicle emissions include : (Rammont, 1999).

1) Introduction of unleaded gasoline at prices below than leaded gasoline (introduced in May 1991).
2) Reduction of the maximum allowable lead in gasoline from 0.4 to 0.15 grams per liter (effectives as of January 1, 1992).
3) Plan to phase out leaded gasoline by 1996.
4) Reduction of the sulfur content of diesel fuel from 1.0 to 0.5 percent as of April 1992 in the Bangkok Metropolitan Area, and after September 1992 through the whole country. The use of low-sulfur diesel fuel has been mandatory in Bangkok since September 1993.
5) Reduction of the 90 percent distillation temperature of diesel fuels from 370 C to 357 C as of April 1991 through the whole country.
6) Requirement for all new cars with engine larger than 1600 cc to meet the European Community Type Performance (ECE R) 83 standards after January 1993; all cars were required to compare after September 1, 1993.
7) Taxis and tuk-tuks have already been largely converted to operate on Liquid Petroleum Gasoline (LPG)
8) ECE R 40 requirements for motor cycles were introduced in August 1993 and followed soon afterward by ECE R 40.01; the government has justed decided on a third step of control which phased-in starting in 1995.
9) ECE R 49.01 standards for heavy-duty diesel engine vehicles are now in effect.

Further investigations are underway to introduce more stringent standards for motorcycles, as well as, for light and heavy trucks, and to purchase 200 CNG (Compressed

Natural Gas) buses to reduce to smoke problem. Currently, emission testing are required and are conducted under the Land Transport The Pollution Control Department (PCD) has Department's general vehicle inspection program. All new vehicles are subject to such inspections. It was expected that the Land Transport Department (LTD) require all in-use vehicles to be inspected, starting in July 1994 (Rammont, 1999).

2.11 Monitoring Program for Gasoline Cars Exhaust Emissions in Bangkok

Monitored the pollution from xhaust emission at idle mode of vehicle in Bangkok Metropolis and vicinity in 1998. The results are shown in Table 2.11. The sample cars were passenger cars and taxis, which had gasoline engine type.

2.12 Driving Cycles

Exhaust emission test are supposed to furnished quantitative data concerning the exhaust emissions and fuel economy to be expected from a vehicle in operation on the road without the necessity of having to problem measurements during an actual drive on the road. For this reason, all exhaust emission test procedures are based on the principle of simulation, i.e., an effort to imitate operating conditions on the road on a dynamometer. This is based on the assumption that the emissions or the fuel consumption will be the same on a dynamometer and on the road, provided that the sequence and mean magnitude of forces and speeds acting on the vehicle are the same as well. Under these conditions, exhaust emissions and fuel economy tests necessitate the use of driving cycles whose speeds and acceleration phases come as close as possible to duplicating the mean of actual driving conditions on the road. Driving cycles are therefore curves of speed via time with specified tolerances (Klingenberg, 1996).

2.12.1 Development of Driving Cycles

The first step towards the development of a driving cycle is always the definition of the traffic conditions to be simulated. The selection of the traffic conditions to be simulated or the corresponding roads has a decisive influence on the exhaust emissions measured in an exhaust emission test. What conditions are actually to be simulated should depend on the impact on air quality caused by exhaust emissions on certain types of road as well as the number of people affected by it. Once a route has been selected, driving tests are run on this route in order to get recordings of driving speeds as a function of time. These test drives are made with vehicles of various classes as well as by drivers of various driving behaviors (Klingenberg, 1996).

The selection of the traffic conditions to be simulated or the corresponding roads has a decisive influence on the measurements in an exhaust emissions test. What conditions are actually to be simulated should depend on the impact on air quality caused by exhaust emissions on certain types of road as well as the number of persons affected by it. Thus, for instance, city centers as well as intra-urban streets might be selected for a driving cycle. Once a route has been selected, driving tests are run on this route in order to get recordings of driving speeds as a function of time. These test drives are made with vehicles of various classes as well as by drivers of various driving behavior.

Table 2.8 Roadside Air Quality in Bangkok in 2000

Pollutants	Air Pollutant Concentration				
	Range	95 Percentile	Average	Standards	Exceeding Standards
TSP (24-hr) mg/m^3	0.05 – 0.48	0.35	0.19	0.33	(5.9) 25/424
PM-10 (24-hr) $\mu g/m^3$	27.0 – 244.4	146.6	82.6	120	(12.8) 206/1613
CO (1-hr) ppm	0.00 – 18.50	5.60	2.20	30	0/41879
CO (8-hr) ppm	0.00 – 13.13	5.17	2.19	9	(0.1) 34/42452
Pb (24-hr) $\mu g/m^3$	0.01 – 0.57	0.21	0.10	- -	- -
Pb (monthly) $\mu g/m^3$	0.03 – 0.24	0.16	0.09	1.5	0/62
O_3 (1-hr) ppb	0.00 – 136.0	31.0	7.6	100	(0.02) 5/23615
SO_2 (1-hr) ppb	0.00 – 120.0	24.0	9.2	300	0/22988
SO2 (24-hr) ppb	0.00 – 38.0	19.2	9.2	120	0/994
NO_2 (1-hr) ppb	0.00 – 169.0	81.0	35.4	170	0/22962

Note From http://www.pcd.go.th

Table 2.9 Ambient Air Quality in Bangkok in 2000

Pollutants	Air Pollutant Concentration				
	Range	95 Percentile	Average	Standards	Exceeding Standards
TSP (24-hr) mg/m^3	0.02 – 0.33	0.19	0.09	0.33	0/351
PM-10 (24-hr) $\mu g/m^3$	18.6 – 69.4	102.7	56.1	120	(2.1) 37/1725
CO (1-hr) ppm	0.00 - 12.5	2.60	0.96	30	0/70186
CO (8-hr) ppm	0.00 - 8.20	2.31	0.97	9	0/71609
Pb (24-hr) $\mu g/m^3$	0.01 - 0.44	0.24	0.09	- -	- -
Pb (monthly) $\mu g/m^3$	0.02 - 0.33	0.21	0.09	1.5	0/93
O_3 (1-hr) ppb	0.00 - 203.0	54.0	15.6	100	(0.3) 161/54415
SO_2 (1- hr) ppb	0.00 - 161.0	20.0	6.7	300	0/72750
SO_2 (24- hr) ppb	0.00 - 76.4	15.7	6.7	120	0/3062
NO_2 (1- hr) ppb	0.00 - 136.0	53.0	22.8	170	0/67094

Note From http.//www.pcd.go.th

Table 2.10 Emission Standards for In-Use Motor Vehicles in Thailand (Gasoline Vehicle)

Type	Pollutants	Standards	Equipment	Methods
- Register before November 1, 1993	CO HC	4.5% 600 ppm.	Non-Dispersive Infrared Detection	Measure while parking the car at idle and no load
- Register after November 1, 1993 All Type	CO HC	1.5% 200 ppm.		

Note From http://www.pcd.go.th

From the multitude of driving cycles that recorded, a single curve is selected, which is as representative as possible. This is done by means of visual assessment of speed curves as well as by using a number of quantitative criteria summarily characteristic of the driving cycle in question. Among the criteria most frequently used are average speed and the proportions of time spent idling, accelerating, decelerating and at a constant speed. The selected curve is then modified as required, for accommodation, which represent the performance limits of the dynamometer used (Klingenberg, 1996). On the whole, the US-75 driving cycle was arrived at in this fashion (Figure 2.13).

As an alternative, it is possible to draw up a "synthetic" polygonal driving cycle. This is done by subdividing the driving curves recorded into a number of driving modes according to one of several different procedures, and establishing their frequency and in some cases, even their typical sequence. Some of these individual driving modes are then selected according to their frequency and combined into a representative driving cycle. Although much computing is required for this procedure, it is mainly independent of the length of the test track, and the resultant driving cycle can be varied within wide limits, yet simplification and schematization should not be taken too far. The European driving cycle was developed along these lines. (Figure 2.14) Moreover, the two methods - selecting and constructing - may be combined.

Constructing driving cycles for the categories described from records of values measured during drives in traffic allows theoretically infinite possibilities of selections and thus of the patterns of driving cycles; consider, for instance, the sequence of selected driving cycle phases.

Furthermore, it is nearly impossible to simulate extreme traffic conditions, such as traffic jams, by means of only one driving cycle because only statistically determined mean values of driving behavior, data from drivers, traffic flow, cities, roads and road inclinations can be used.

Table 2.11 Emission Standards for New Vehicle in Thailand

Type	Level	Reference Standards	Standards No.	Gazette	Enforced	
1. Gasoline Engine Vehicle	5	94/12/EC	TIS.1440-1997	Vol.114 Part 90 dated November 11, 1997	January 1, 1999	
	6	96/69/EC Ref.Weight not more than 1,250 kg. Ref.Weight more than 1,250 kg.	TIS.1870-1999	-------------------------	October 1, 1999* October 1, 2000*	
2. Light Duty Diesel Engine Vehicle	4	94/12/EC For Direct Injection Engine	TIS.1435-1997	Vol.114 Part 90 dated November 11, 1997	January 1, 1999 September 30, 2001	
	5	96/69/EC Ref.Weight not more than 1,250 kg. Ref.Weight more than 1,250 kg. For Direct Injection Engine	TIS.1875-1999	-------------------------	October 1, 1999* October 1, 2000* September 30, 2001*	
3. Heavy Duty Diesel Engine	2	95/542(A)/EEC (EURO 1.)	TIS.1290-1995	Vol.112 Part 77 dated September 26, 1995	May 12, 1998	
	3	95/542(A)/EEC (EURO 2.)	TIS.1295-1998	Vol. 112 Part 77 dated September 26, 1995	May 23, 2000	
4. Motorcycle	3	HC not more than 5 g/km.	TIS.1360-1996	Vol.113 Part 25 dated March 26, 1996	All Sizes	July 1, 1997
	4	CO not more than 4.5 g/km. HC + NOx not more than 3 g/km. White Smoke not exceed 15 % Volatile Organic Compound not exceed 2 g/test	TIS.1650-1998	Vol.116 Part 57 dated July 20, 1999	Not more than 110 cc. Not more than 125 cc. 150 cc. up	July 1, 1999 July 1, 2000 July 1, 2001

Note: http://www.pcd.go.th

Table 2.12 Exhaust Emissions Monitoring Program in Bangkok Metropolis and Vicinity

Type of Gasoline Cars	**Carbon Monoxide**		**Hydrocarbon**		**Noise**	
	Average (%)	Exceed Standard (%)	Average (ppm)	Exceed Standard (%)	Average (dBA)	Exceed Standard (%)
Passenger Car						
-with catalytic converter	0.31	6.04	4.3	2.35	86.9	0
-without catalytic converter	2.1	6.5	1.84	2.1	87.9	0.84
Taxi						
-with catalytic converter	1.24	25.32	195	29.11	86.57	0.25
-without catalytic converter	2.23	15.25	280	7.5	87.8	1.25

Note From Passenger Car Emission in Relation to Traffic Volume Rammont, 1999.

Remark: 1. Catalytic converter car standard is CO < 1.5% and HC < 200 ppm.

2. Non-catalytic converter car standard is CO < 4.5% and HC < 600 ppm.

3. Noise standard < 100 dBA (at distance 0.5 meters with 45 degree of tail pipe)

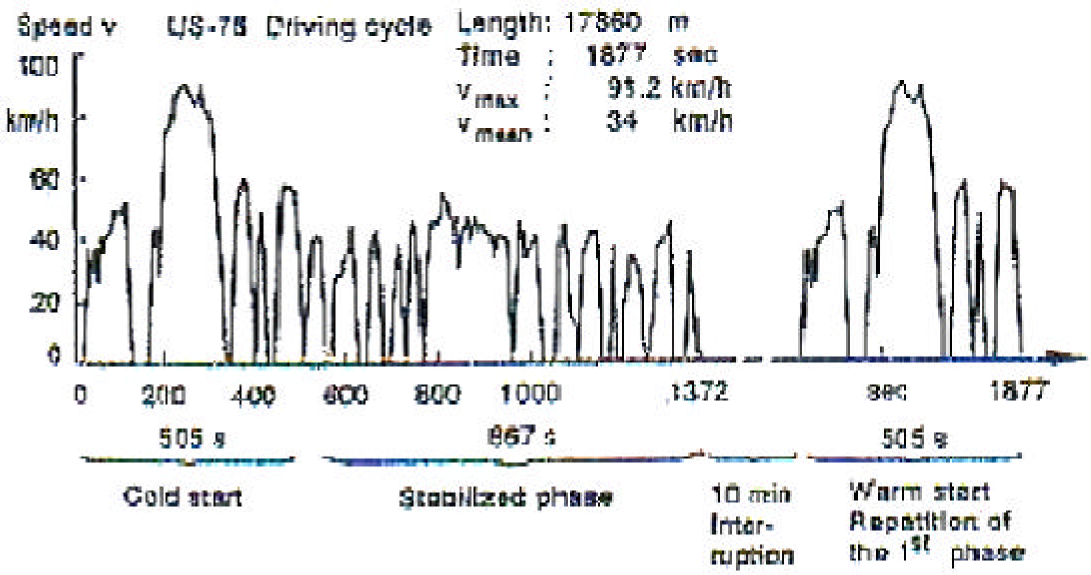

Figure 2.13 Driving cycle of the US-75 test; speed vs time t (Source: Klingenberg, 1996)

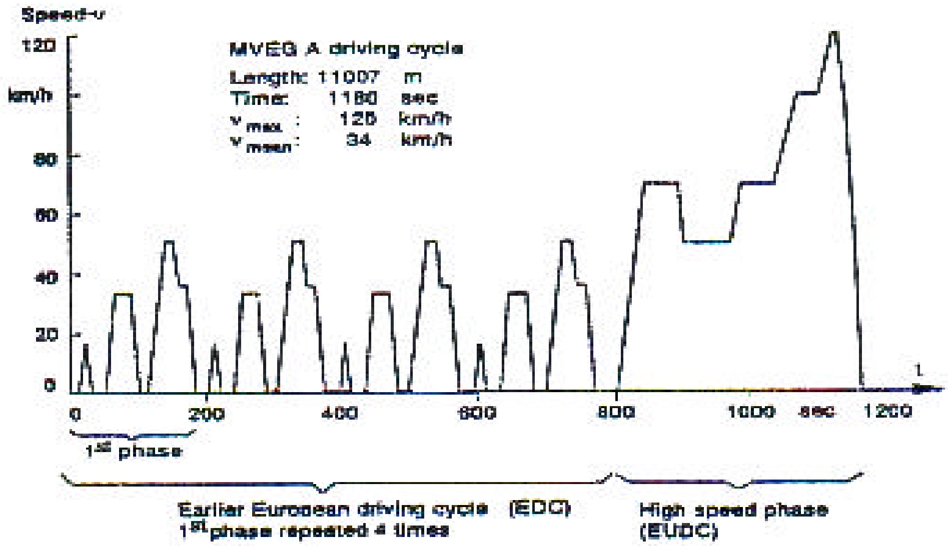

Figure 2.14 New European driving cycle (Source: Klingenberg, 1996)

To determine the exhaust emissions according to the US-75 test or to the European test, the vehicles are tested in a "cold start" after conditioning them in a room at a temperature of approximately 20°C for 12 h (for the US test) and 6 h (for the European test). To determine the fuel consumption, no conditioning is required and the vehicles are started with a hot engine (warm start).

The new European driving cycle, valid for the European Union (EU) from 1993 onwards, includes a high speed phase to enable simulation of drives on extra-urban roads and highways. This high speed phase has been added to the former European driving cycle which consists of 4 identical phases.

For the US-75 test, unlike the new European driving cycle, a separate driving cycle is regulated for the high speed phases, the so called Highway Driving Cycle (HDC). Its curve is shown in Figure 2.15. Again, a warm start is used. In Figure 2.15 details of the test procedure are listed.

2.12.2 Results of Test Runs

The test evaluated here were run by several European automobile manufacturers in a number of European cities as a part of traffic noise study. For this purpose, it was necessary to analyze typical urban traffic. The test routes were selected by the manufacturers without prior consultation, a fact which made basic differences in driving behavior probable. Figure 2.16 shows these criteria for test routes and driving cycles.

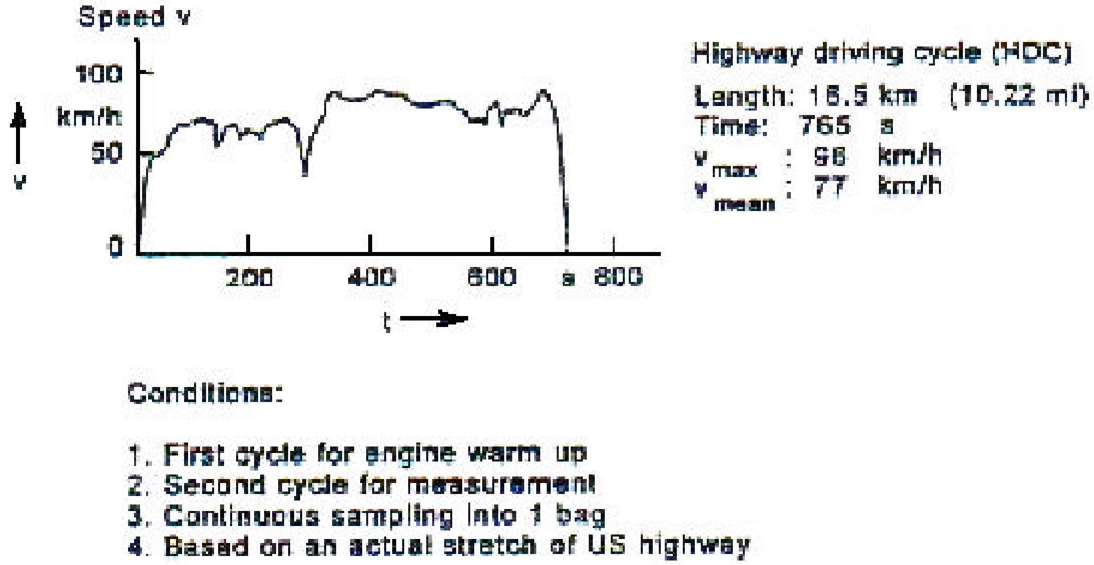

Figure 2.15 US Highway driving cycle (HDC) (high speed driving cycle) (Source: Klingenberg, 1996)

2.12.3 Proposal for a New Worldwide Standard Driving Cycle

There are many proposals to standardize the driving cycles for worldwide use. Figure 2.17 shows a new driving cycle developed by VW for worldwide use (bottom curve) compared to the known driving cycles.

This new driving cycle was developed on the basis of the US-72 cycle and consists of two identical sections. Its development procedure is described in literature.

Unfortunately, for political reasons it is nearly impossible to introduce such as a proposal worldwide. Discussions on this proposal in the UN did not lead to a consensus of opinion among the representatives of all countries.

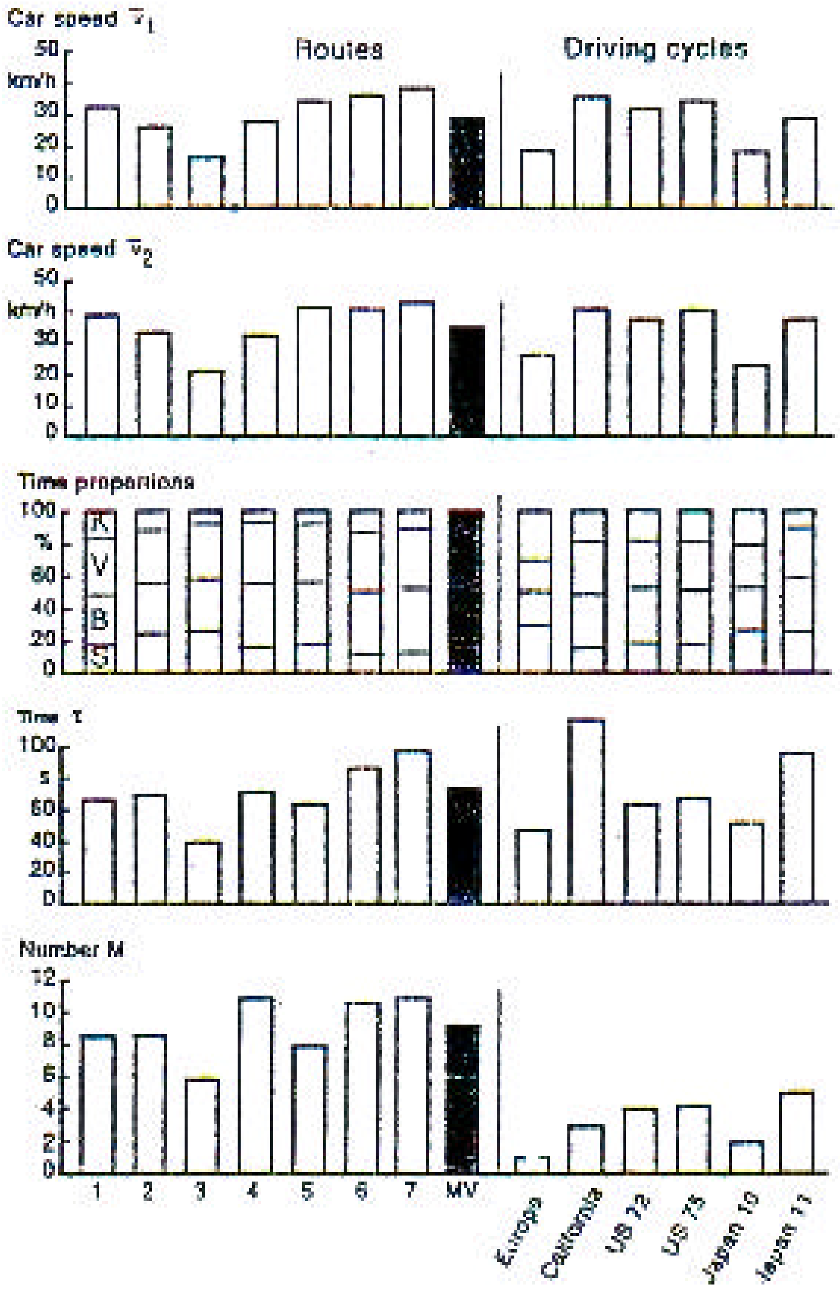

Figure 2.16 Assessment of test routes 1 through 7 and of the mandatory driving cycles according to the assessment criteria. MV are the corrected overall mean values of the respective criteria for the routes. (Source: Klingenberg, 1996)

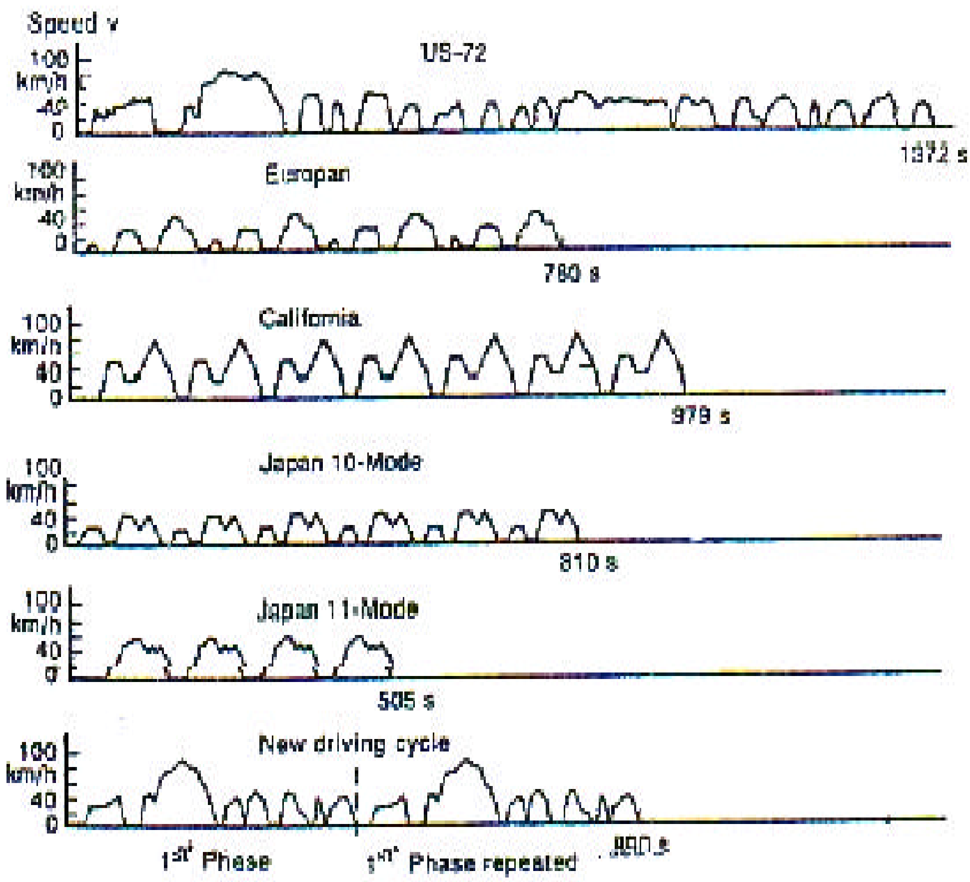

Figure 2.17 Newly proposed driving cycle (bottom) compared to known driving cycles (Source: Klingenberg, 1996)

2.13 Chassis Dynamometer

The chassis dynamometer permits the simulated operation of a vehicle under road conditions. It is essentially a treadmill, with rollers on which the driving wheel of the vehicle are placed. The dynamometer is equipped with a hydraulic power-absorption unit and, for the purposes described here, with a flywheel so the vehicle may be driven under conditions encountered in road service. It may be used to provide exhaust samples from a car that idles, accelerates, cruises, and decelerates in a manner similar to that expected from a driven pattern on city streets. An important factor of the test is the chassis dynamometer with a suitable brake, e.g. a water brake, an eddy current brake or a direct current brake. To produce driving conditions similar to those on the road on a chassis dynamometer, the inertial weights (weight of the vehicle and weight of the vehicle's rotating parts) are simulated by coupled gyrating masses (flywheels) and the total resistance to motion is simulated by a defined braking of the dynamometer with a suitable brake. Figure 2.18 shows the principal configuration of such a dynamometer.

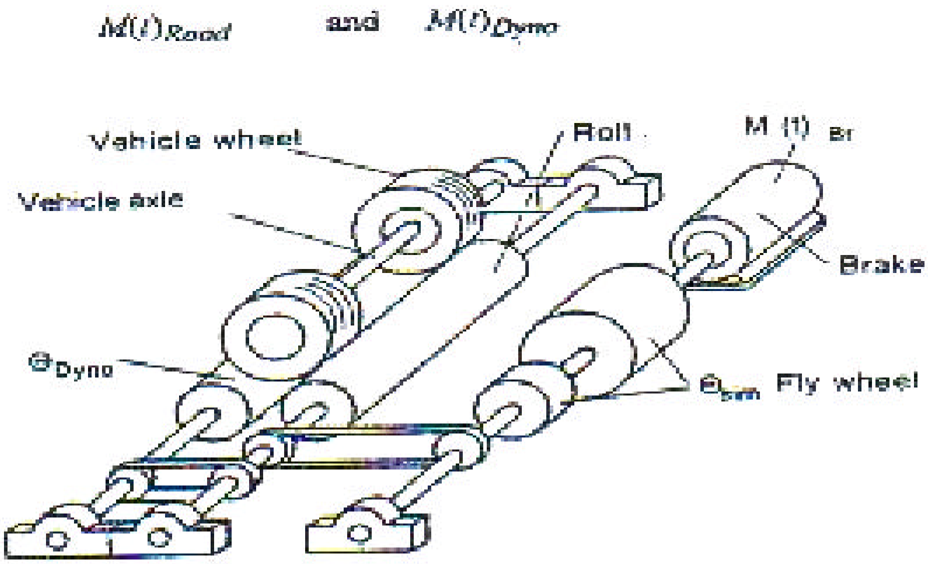

Figure 2.18 Principal configuration of a chassis dynamometer. M = torque, Θ = inertial moment, m= mass (Source: Klingenberg, 1996)

This figure shows two rolls on the left with the live axle with two drive wheels above them. On the right, the flywheels and the brake are outlined.

The established chassis dynamometers are equipped with digital control circuits, a controlled DC electrical device as a brake, adjustable mechanical flywheels, and electronic simulations of small gyrations between the flywheels.

2.14 Exhaust Emission Tests

An overall picture of an exhaust emission test is shown in Figure 2.19. A vehicle is placed on a chassis dynamometer behind a cooling fan. The test is performed with opened hood. The driver is watching a driving cycle displayed on a screen (driver's aid) above the vehicle and is driving the vehicle accordingly. On the extreme right the measurement and control units are located in a separated cabin. At the back of the laboratory the dilution tunnel, pump and the bags are installed. Calibration gas cylinders are placed against the back wall.

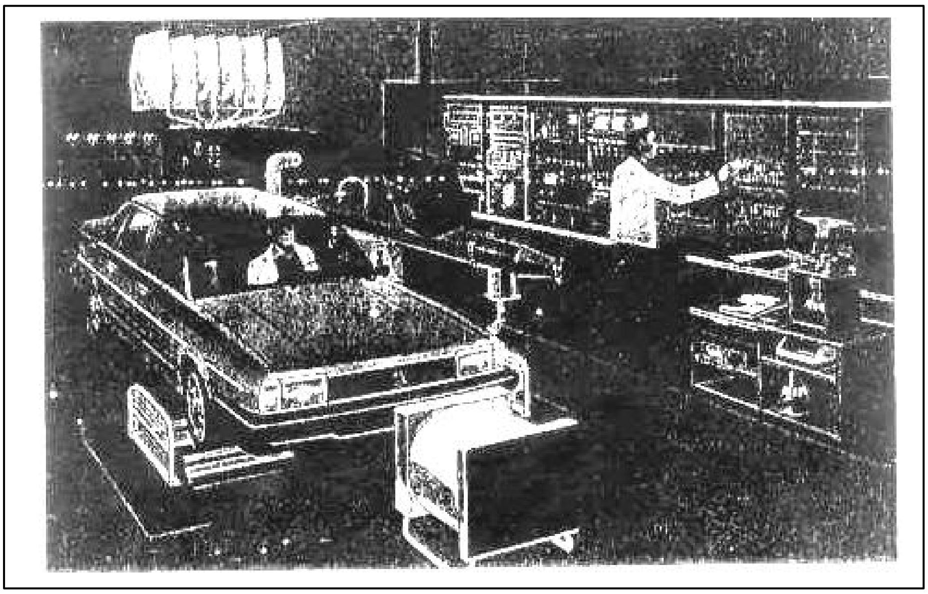

Figure 2.19 Phantom drawing of an exhaust emission laboratory (Source: Klingenberg, 1996)

Test Techniques

The block diagram of Figure 2.20 gives a schematic overview of the important parameters and component parts of an exhaust emission and fuel consumption test. First of all, the vehicle, the specified test fuel and the devices for simulation of driving on a road have to be mentioned:

1. vehicle (tire pressure is checked)
2. test fuel
3. driver
4. driving cycle
5. chassis dynamometer including fly wheel and brakes.

As ambient parameters:

1. air humidity
2. room temperature
3. atmosphere pressure

have to be taken into account

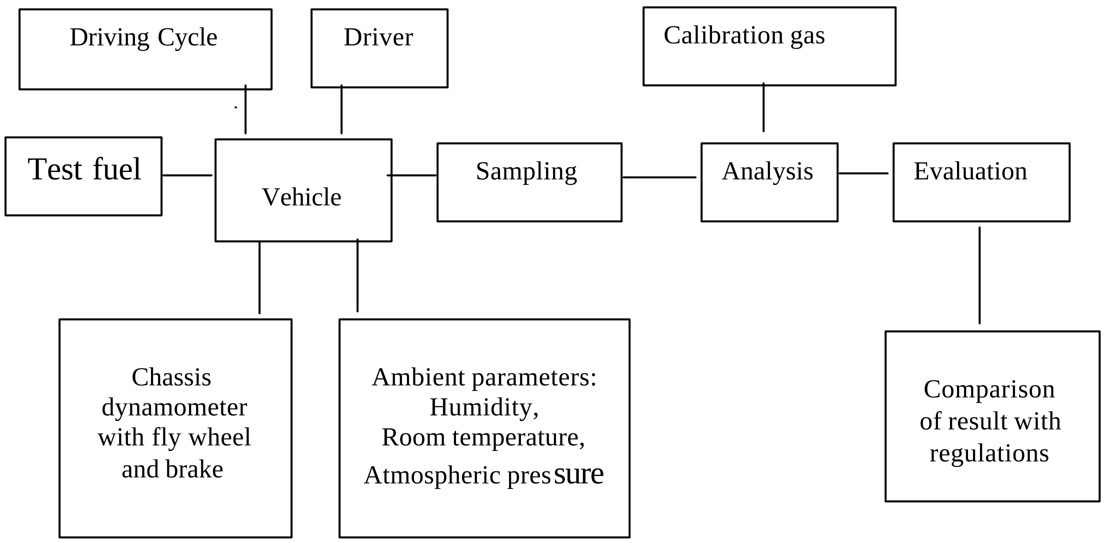

Figure 2.20 Overview of parameters and component parts, schematically (Source: Klingenberg, 1996).

The analytical sampling, i.e., the technique of obtaining a gas probe includes the

1. Dilution device with dilution tunnel and CVS-unit also used for measurement of the volume flow rate of the exhaust gas,
2. Isokinetic sampling of gas probes from the dilution tunnel,
3. Bags for gas probes.

The technique of analyzing exhaust emission gas components requires:

1. HC measurement
2. CO measurement
3. NO_X measurement
4. CO_2 measurement
5. O_2 measurement
6. Calibration

The evaluation gives the corresponding measurement result of each gas component in mass per distance driven. The test can be described in the detail as follows:

- The vehicle is driven on to a chassis dynamometer simulating the road load on
- the engine, i.e. the total resistance to motion.
- The driver watches a so-called driving cycle consisting of phases of acceleration deceleration and idle and runs the vehicle according to this cycle, remaining within specified tolerances.

- The escaping exhaust gas is diluted by air.
- The concentration of the corresponding components are measure with the analyzers. (Klingenberg, 1996)

2.14 Related Studies

Rapone et al., (1995) carried out investigation for experimental evaluation of fuel consumption and emission in congested urban traffic in different conditions of a specific area. The experimental methodology used for the evaluation of emission consisted : a) recording on-road car and engine operating conditions during designed trips performed in the center of Naples (Italy) by an instrument car, b) determining, by multivariate statistical analysis, driving cycles characterizing typical traffic conditions, and c) measuring emissions and fuel consumption in laboratory using defined driving cycles. Fuel flow rate measurements were performed at each second, while emissions were detected along a cycle and, an average value per kilometer was obtained. Opening conditions of engine during laboratory testing were related to on-road operating conditions by comparing fuel consumption and exhaust gas temperatures measurements performed on-road and in laboratory by the same devices.

Sparis et al., (1995) studied the three-way catalytic converter performance under a stepwise constant idle speed schedule. The results indicated that as the catalyst efficiency deteriorated with age, the rise of pollution levels was accompanied by significant changes in the CO and temperature difference signals. The HC signal was not as strongly affected. There were positive indications that the outlet-inlet temperature difference signal could be used as an input to a micro control catalyst efficiency assessment system, capable of operating under driving conditions. However the further experimentation was required for the development of the catalyst efficiency evaluation algorithm, since under load the increased mass flow and exhaust gas temperature would strongly effect catalytic efficiency.

Sugira et al., (1995) developed a multi-dimensional numerical method for predicting warm up characteristics of automotive catalytic converter systems to achieve low tail pipe emissions with satisfactory packagability. The experiment verifications of the method were conducted to assure the accuracy of it. This method was able to predict a transient thermal response of catalytic converter systems qualitatively. The effort of design parameters such as electrically heated catalyst (EHC), high loading of noble metal, and thin honeycomb wall on warm-up characteristics of the catalyst were analyzed.

In a study by Rammont (1999), relationship between the passenger cars emissions and the traffic volume in BMR was investigated. This research concluded that the air quality is not directly related to high traffic volume. However, it is affected by the traffic congestion conditions, speed, meteorological conditions, and the surrounding area. In the same study, the exhaust emission from cars with a catalytic converter were measured while simulated test runs were performed on a chassis dynamometer using a Bangkok driving cycle and at idle condition. The results showed that exhaust emissions were higher for CVS system non-catalytic converter cars than cars with catalytic converter, except for CO_2 emission.

Cadle et al., (2001) conducted some experiments on in-use light-duty gasoline vehicle particulate matter emissions on three driving cycles tested in Denver, Colerado (USA), using the US federal test procedure (FTP), a hot start unified cycle (UC), and the REPOS driving cycles at 35°F. All vehicles were 1990-1997 model year which were tested on both an oxygenated and a nonoxygenated fuel. Three of the high emission vehicles had emission rates near the 30 g/mi CO (minimum 33.4, 35.0, and 37.7 g/mi, respectively). The other three high emitters had CO emission rates of 125, 243, and 354 g/mi, respectively. This study indicated that the driving cycle had a significant impact on the distribution of the emitted polynuclear aromatic hydrocarbons.

Aranyasri (2002), tested sulfur's effect in gasoline fuel on exhaust pollutions emitted and on-board diagnostic. The results showed that in case of using gasoline fuel composting 800 ppm sulfur not found OBD showed alarm signal in Japanese car but for European car showed alarm signal during using 800 ppm sulfur but not showed when using 500 ppm sulfur in gasoline fuel. The pollutants increased when use high sulfur in gasoline fuel in 1-4 times compare with 150 ppm sulfur the reduction of sulfur in fuel made the pollutants decrease. Catalytic converter can be reversible when using low sulfur but the level of reversible and pollutants will be different depend on the technology of catalytic converter.

Meenguen and Limpaseni (2002) studied emission estimates and species of volatile organic compounds from motorcycles. The results from the study concluded that the ages of MC and maintenance did not affect the BTEX emissions but the engine condition did. The present maintenance procedure does not aim at reducing emissions. Before maintenance BTEX average emissions from 2-stroke MC were 790, 1550, 75, and 245 mg/km respectively while BTEX/THC ratio in the exhaust was 28.55 percent. After maintenance BTEX average emissions did not charge at 95 percent confidence level.

Pawamart and Palaend (2002) studied the efficiency of simple catalytic converter ; Hot Tube, installing with three wheelers or Tuk-Tuk for the purpose of emission reduction.

The results from the study indicated that hot tube had reducing efficiency for pollutants such as HC and CO in 24-30 % and 53-65 %, respectively. While testing on chassis dynamometer hot tube can reduce HC in 18-29 %, HC in 20-46% and NO_x in 0.16-25%. There is no effect for engine performance during operation. Also with fuel consumption there is no significant different. Exhaust temperature increase twice from hot tube HC combustion in exhaust pipe.

Chapter III
Research Methodology

3.1 Selection of Traffic Routes

Three routes of traffic in BMR were selected for this study as shown in Figure 3.1 The details of traffic routes are shown below:

Route 1 : Future Park Rangsit - Donmung Airport (distance 8.7 km).

Route 2 : Future Park Rangsit - Laksi Monument (distance 14.7 km).

Route 3 : Laksi Monument - Kasetsart University (distance 4.5 km).

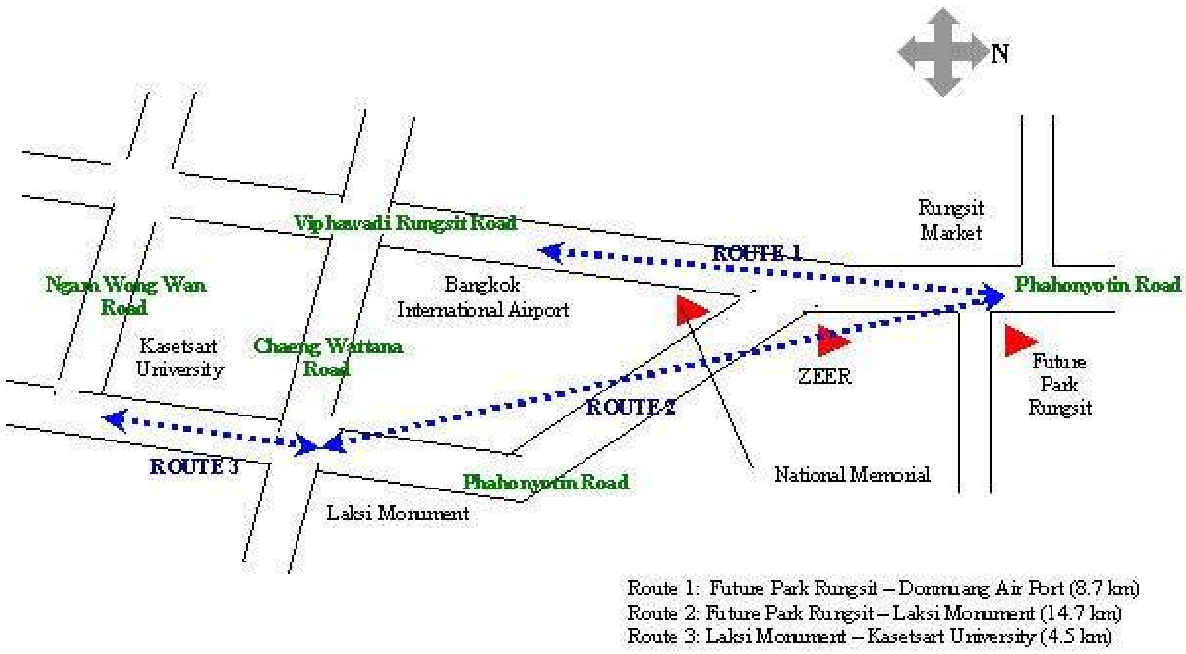

Figure 3.1 Driving Cycle Tests Route Map

3.2 Driving Cycles

Driving cycles for Bangkok Traffic along the three selected routes were obtained by driving runs with three test cars. The three driving cycles were obtained for the total time duration of each cycle covering a distance of 8.7 km.,14.7 km., and 4.5 km., respectively. The average and maximum speeds in km./h was thus determined.

As a matter of practical necessity "driving" of a test was done on a chassis dynamometer with exhaust emission measuring equipment. Power absorption and inertial effects of the dynamometer were set to approximate the power requirements and inertia of a vehicle driven on the road; these dynamometer characteristics were adjusted to vehicle weight.

3.3 Selection of Test Cars

A total of 3 cars manufactured by Mitsubishi of different engine size and manufacturing year were used for this study as shown in Figure 3.2. These test cars were used in to 2 groups, first equipped with catalytic converter and then without any exhaust emission control device. The details of the test cars are given in Table 3.1 below :

Table 3.1 Test cars

List	Equipped with catalytic converter			Without any exhaust emission control device		
	Mitsubishi 1.5 L	Mitsubishi 1.6 L	Mitsubishi 1.8 L	Mitsubishi 1.5 L	Mitsubishi 1.6 L	Mitsubishi 1.8 L
Car Plate No.	พพ6238 กรุงเทพ ฯ	ภท 834 กรุงเทพ ฯ	ภร3752 กรุงเทพ ฯ	พพ6238 กรุงเทพ ฯ	ภท 834 กรุงเทพ ฯ	ภร3752 กรุงเทพ ฯ
Trade Name	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi
Model	Lancer	Lancer	Lancer	Lancer	Lancer	Lancer
Model Year	1996	1999	2000	1996	1999	2000
Capacity (cc.)	1,500	1,600	1,800	1,500	1,600	1,800
Mileage (km.)	80,812	67,000	23,465	80,812	67,000	23,465
Driving Cycle	Obtained Driving Cycle					

3.4 Exhaust Emission Tests

After obtaining the driving cycles along the 3 selected traffic routes (Route 1 : Future park Rangsit - Donmung Airport-distance 8.7 km., Route 2: Future park Rangsit-Laksi Monument-distance 14.7 km. and Route 3: Laksi Monument-Kasetsart University-distance 4.5 km.), the exhaust emission tests were conducted with the 3 test cars on the chassis dynamometer in a laboratory at the Mitsubishi Motor Corporation Sittipol Co.,Ltd. in Klong Luang district of Pathumthani Province of Thailand.

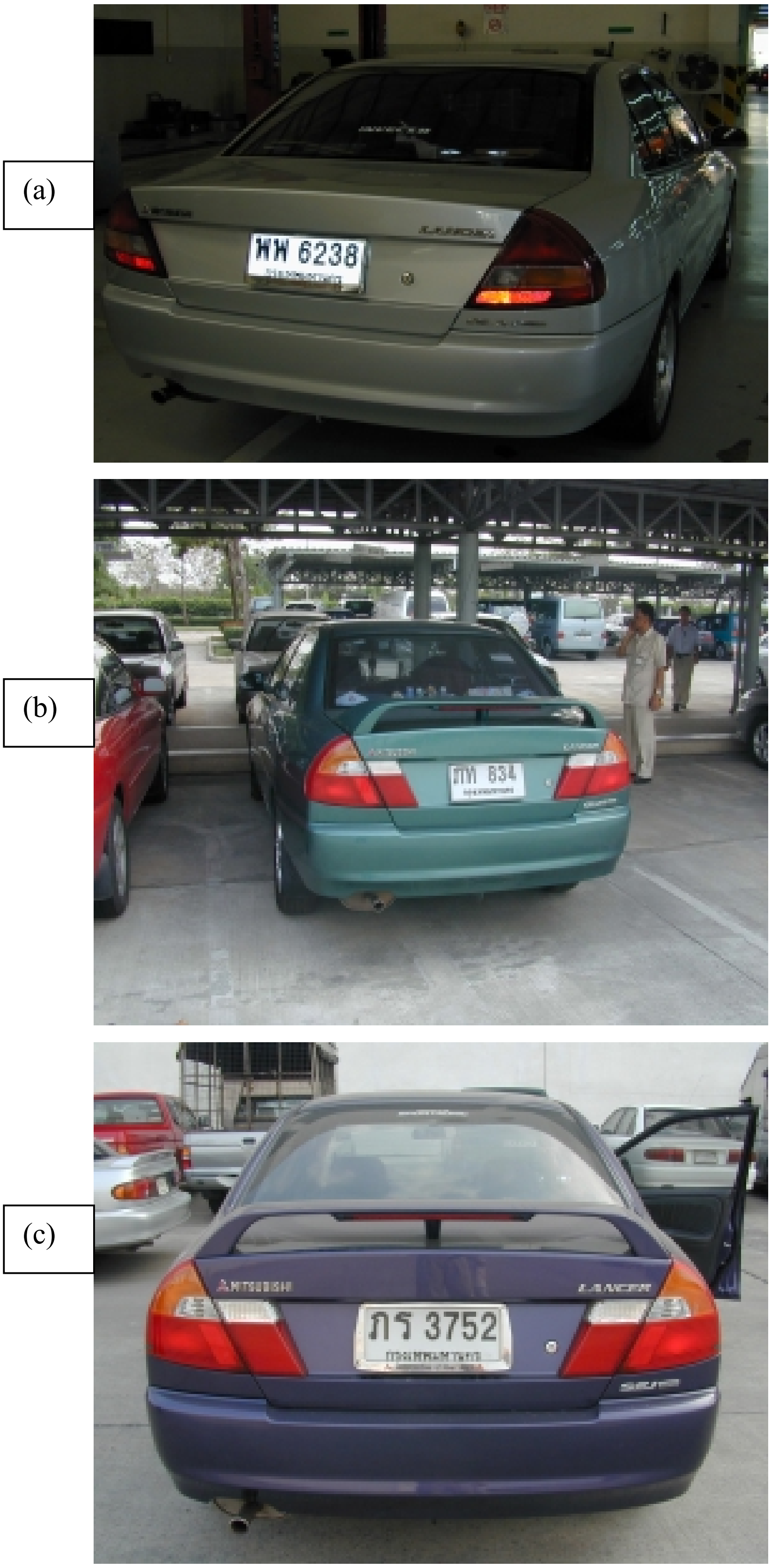

Figure 3.2. Three test cars-Mitsubishi Lancer (a)1.5L, (b)1.6L, and (c)1.8 L

Method for Emission test

1. **Equipment**
    1) Chassis dynamometer (Figure 3.3)
    2) Exhaust Gas Analyzer for CO, HC, CO_2, NO_X, Total particulate matter (TPM) (Figure 3.4-3.5)
2. **Load setting (refer to car model specification)**
3. **Pattern**

    Obtaining driving cycles along the 3 selected routes for this study and taking the average all day driving cycles for suburban BMR.
4. **Procedure**
    1) Pre-conditioning of the engine by idle running on the chassis dynamometer
    2) Simulating the obtained driving cycle pattern on the chassis dynamometer and measuring exhaust gas pollutants (Figure 3.6)
    3) Recording the data by using video tape recorder
    4) Analyzing data for each emission pollutants
    5) Calculation by using mathematical model

Figure 3.3 Chassis dynamometer

Figure 3.4 Exhaust Gas Analyzer for CO, HC, CO_2

Figure 3.5 NO_X Measuring Equipment

Figure 3.6 Driving simulation on chassis dynamometer with pollutants measuring

3.5 Estimation of Emission of Exhaust Gases

For assessing the current situation and predicting future passenger cars exhaust emissions in BMR, it is important to determine $M_{ij}(t)$ for the decade (1996-2006). For such a prognosis, suitable calculation model was used which included the most important influencing factors resulting from the vehicle's specific characteristics, road traffic situations, and vehicle emissions, etc. The prognosis for total emissions was carried out in 3 sections:

- determination of exhaust gas emission factors
- determination of road-related exhaust gas emission factors for specific pollutants
- determination of total emissions.

Exhaust Emission by a mobile source (vehicle type "i" for a pollutant type "j" in year "t") can be expressed using the equation (Gosaarak, 2001)

$$M_{ij}(t) = N_i(t)\, F_i(t)\, FE_i(t)\, EF_{ik}\; S_i(t)\, A_i(t) \qquad (3.1)$$

where,

$M_{ij}(t)$ = Exhaust emission by vehicle type "i" for pollutant type "j" in year "t",(tonne)

$N_i(t)$ = Number of vehicles in operation by vehicle type "i" " in year "t"

$F_i(t)$ = Average fuel consumption by vehicle type "i" in year "t" (L)

$FE_i(t)$ = Fuel efficiency of vehicle type "i" in year "t" (km/L)

EF_{ik} = Exhaust emission factor expressed as the mass of pollutant per unit of distance traveled (g/km)

S_i (t) = Speed correction factor (defined as the pollutant-exhaust-emission rate at any speed to the pollutant-exhaust-emission rate at a specified speed, as determined by the 1975 Federal Test Procedure of U.S.A.) for vehicle type "i" in year "t";

A_i (t) = Age-correction factor (defined as the ratio of the pollutant-exhaust-emission rate at any vehicle-use status in km to the pollutant-exhaust-emission rate at a specified km): $A_i(t)$ is used to adjust for deteriotation of vehicle performance with vehicle age.

$$Vkm_i = F_i(t)\ FE_i(t)\ EF_{ik}\ S_i(t)\ A_i(t) \qquad (3.2)$$

where, $Vkm_i(t)$ is known as average vehicle-kilometer traveled for vehicle type "i" in year "t". Since fuel efficiency is a function of speed and vehicle age (US-EPA, 1973), the average vehicle-km traveled by vehicle type "i" in year "t".

Finally equation (3.1) can be written as (Gosaarak, 2001)

$$M_{ij}(t) = N_i(t)\ vkm_i(t)\ EF_{ik} \qquad (3.3)$$

Total emissions were obtained by multiplying the various terms on the right hand side of equation (3.3)

The number of transport vehicles was calculated by using the following equation :

$$V_p = V_b\ (1+g_r)^{n}{}_{t} \qquad (3.4)$$

where,

V_P = number of a vehicle type in a year "t".

V_b = number of a vehicle type in the base year.

n_t = number of year "t".

g_r = compounded growth rate of a vehicle type.

Chapter IV
Result and Discussions

4.1 Driving Cycle

From the test drive runs, the obtained individual driving cycles on the 3 selected routes are shown in Figures 4.1-4.9. Figure 4.10 shows the overall driving cycle for suburban Bangkok Metropolitan Region (BMR). Figure 4.11 shows the Bangkok driving cycle as obtained by Pollution Control Department.

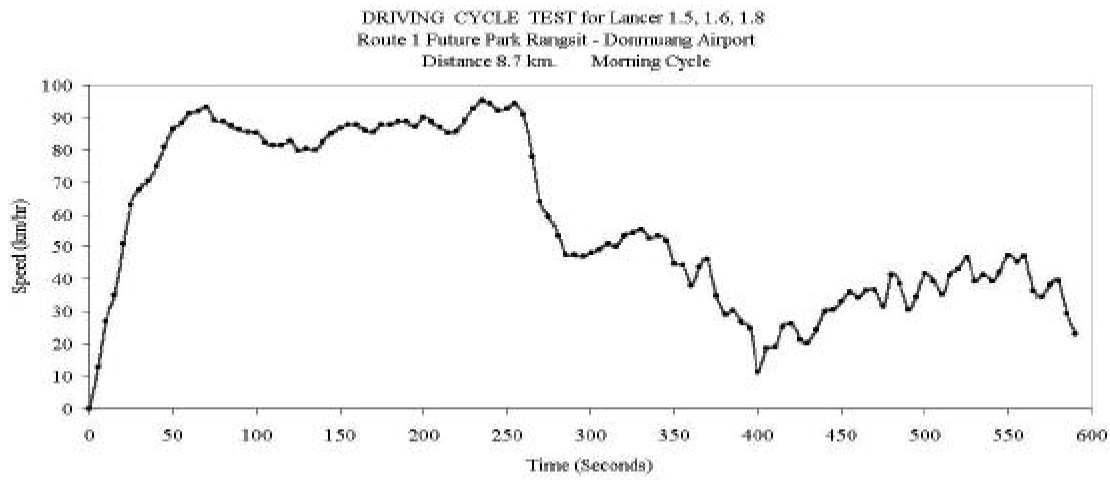

Figure 4.1 Driving cycle for Lancers 1.5, 1.6, and 1.8 on Route 1 Future Park Rangsit-Donmuang (Distance 8.7 km.) Morning Cycle

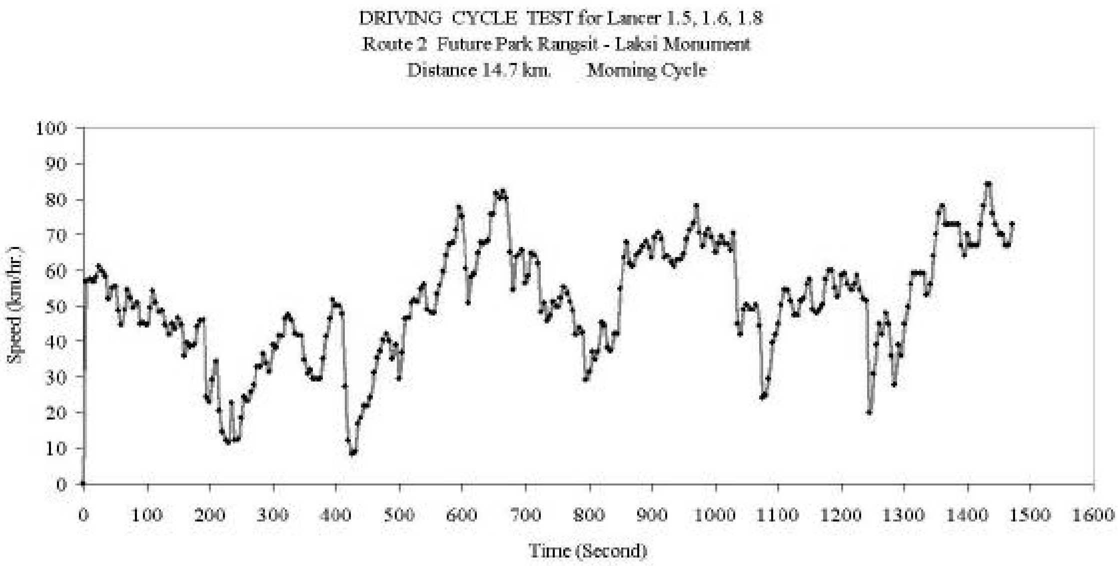

Figure 4.2 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 2 Future Park Rangsit-Laksi (Distance 14.7 km.) Morning Cycle

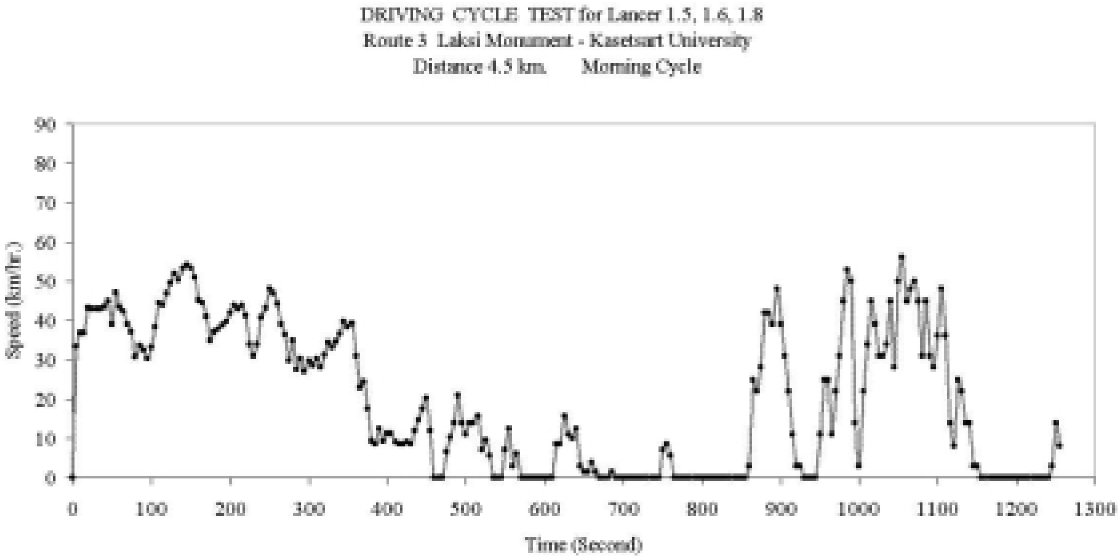

Figure 4.3 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 3 Laksi Monument-Kasetsart University (Distance 4.5 km) Morning Cycle

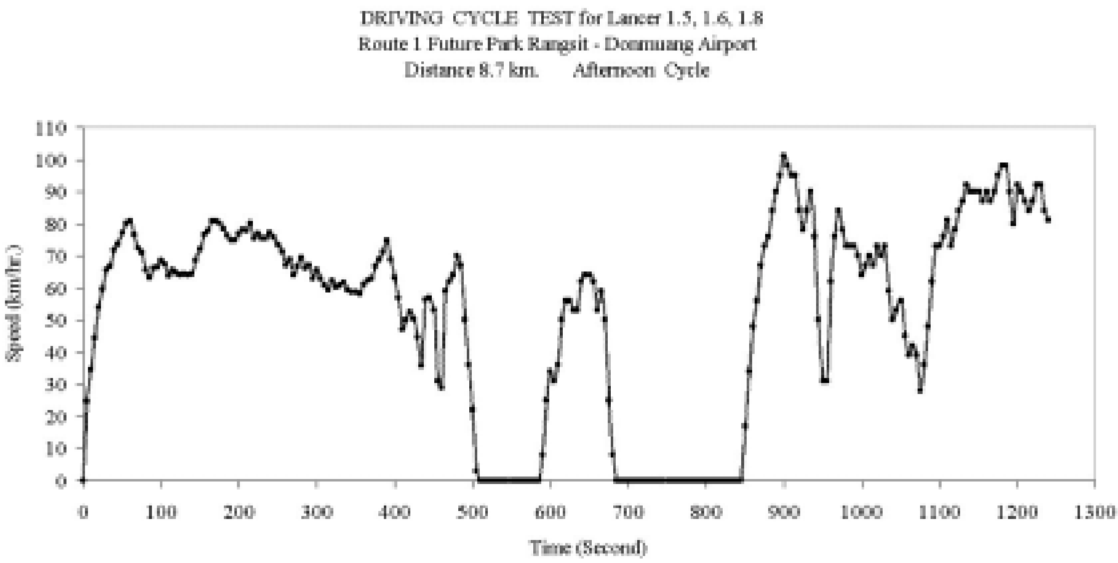

Figure 4.4 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 1 Future Park Rangsit-Donmuang (Distance 8.7 km.) Afternoon Cycle

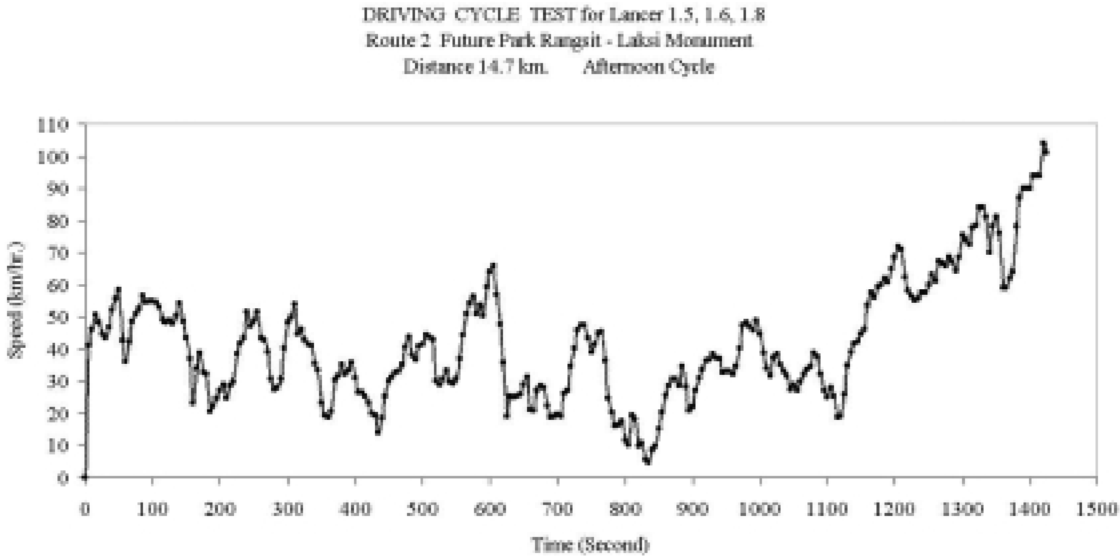

Figure 4.5 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 2 Future Park Rangsit-Laksi (Distance 14.7 km) Afternoon Cycle.

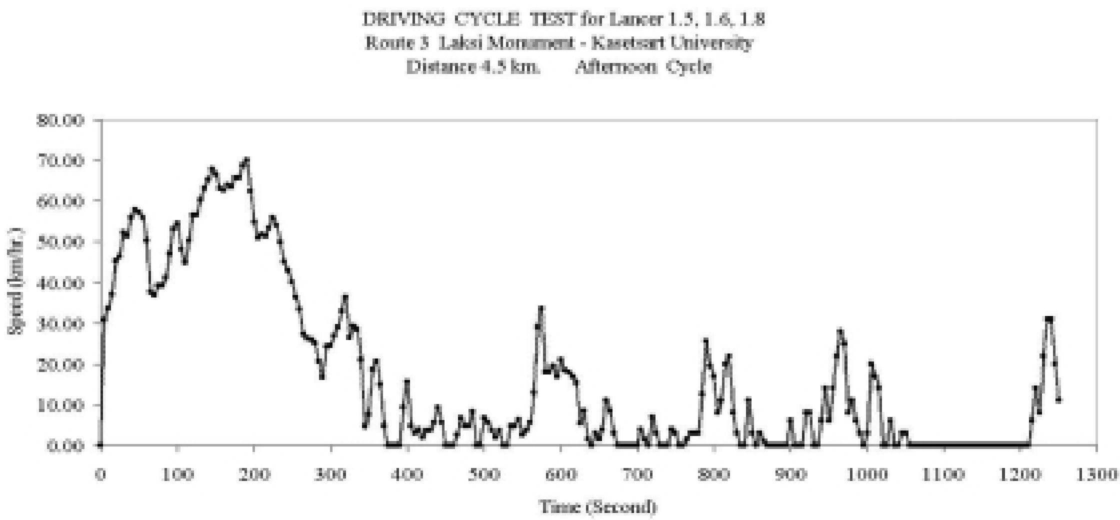

Figure 4.6 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 3 Laksi Monument-Kasetsart University (Distance 4.5 km.) Afternoon Cycle.

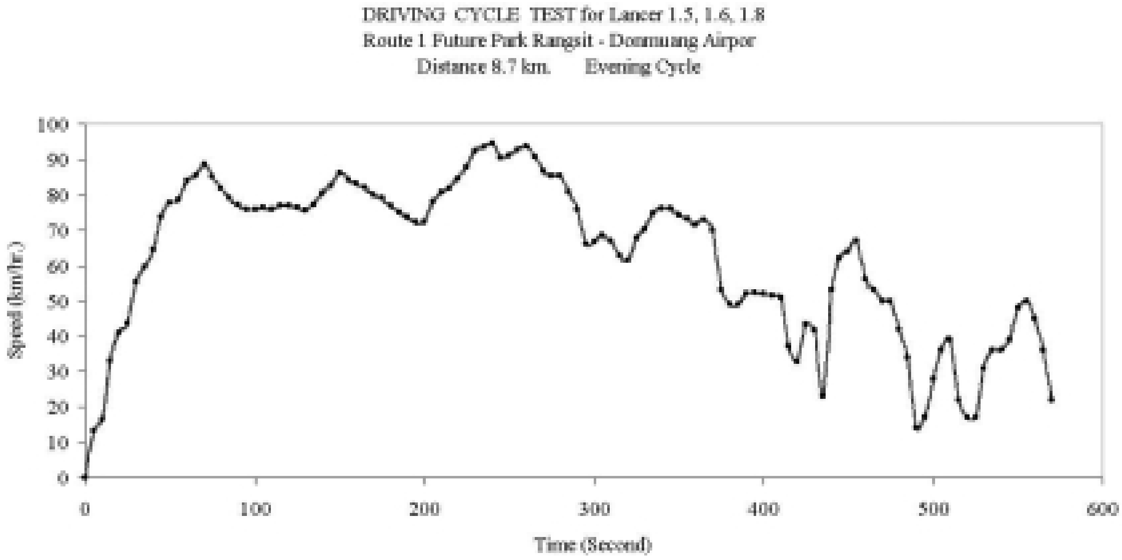

Figure 4.7 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 1 Future Park Rangsit-Donmuang (Distance 8.7 km.) Evening Cycle

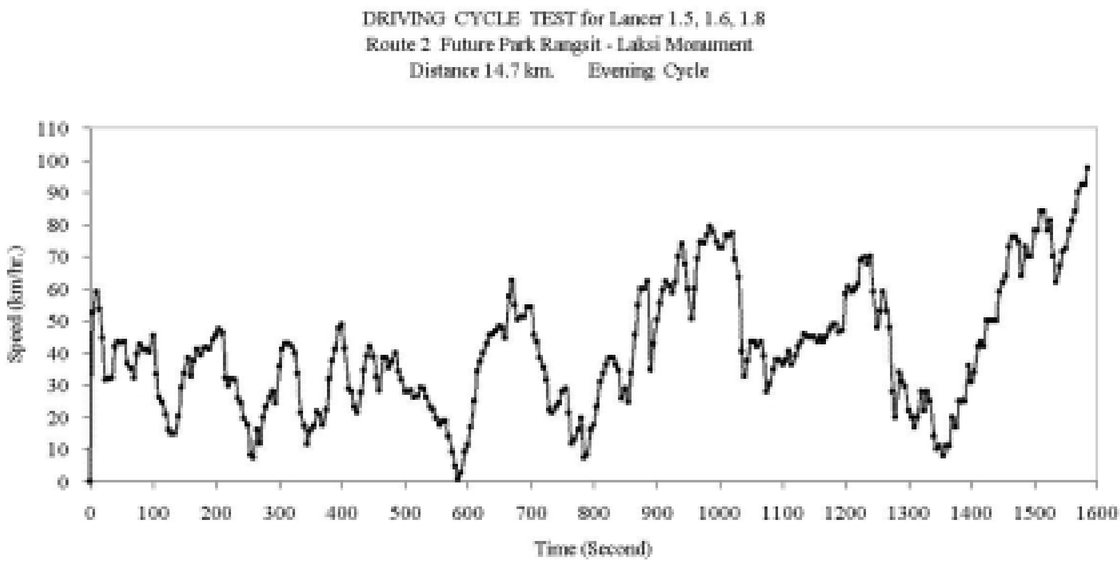

Figure 4.8 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 2 Future Park Rangsit-Laksi (Distance 14.7 km) Evening Cycle

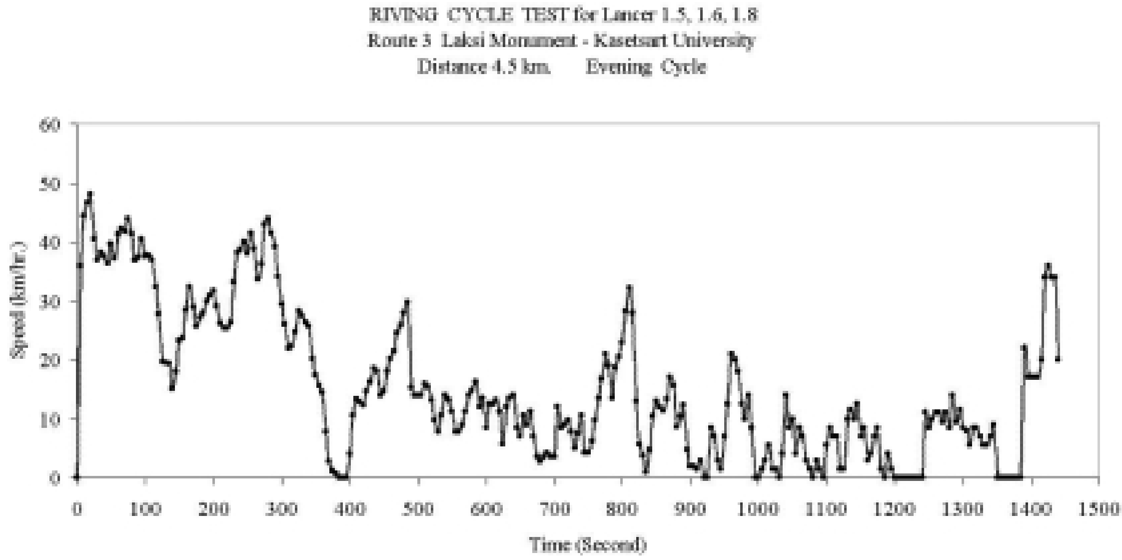

Figure 4.9 Driving cycle for Lancer 1.5, 1.6, and 1.8 on Route 3 Laksi Monument-Kasetsart University (Distance 4.5 km.) Evening Cycle

Based on the results of several driving runs with the test cars along the selected traffic routes in BMR, a driving cycle was obtained as shown in Figure 4.10 Figure 4.11 shows the Bangkok Driving Cycle obtained by Pollution Control Department (PCD) of Thailand.

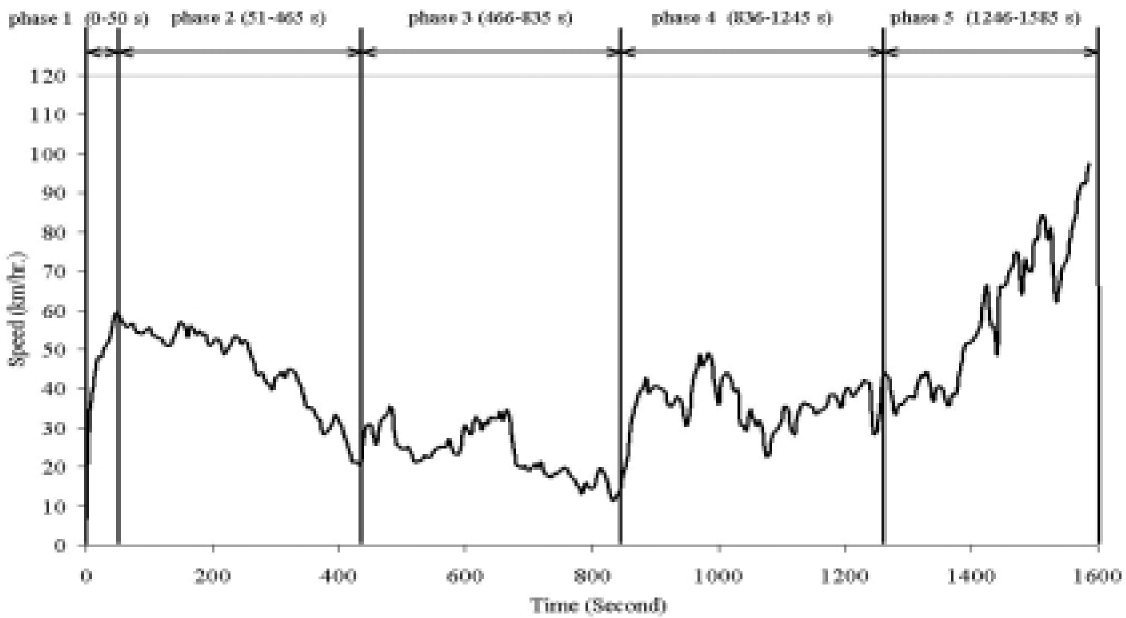

Figure 4.10 Obtained Driving Cycle for Suburban Bangkok Metropolitan Region (BMR)

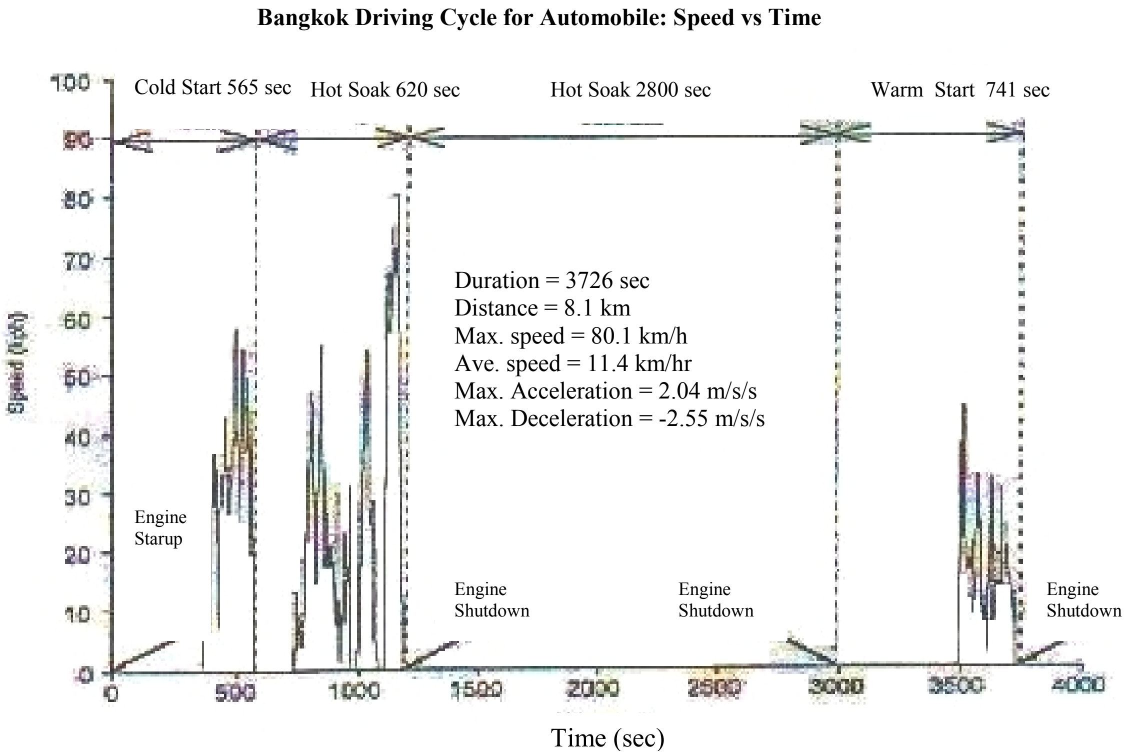

Figure 4.11 Bangkok Driving Cycle (Source: Rammont, 1999)

The average driving cycle in the suburban BMR, based on the tests along the 3 traffic routes selected for this study, was compared with the Bangkok driving cycle as shown in Table 4.1 below.

Table 4.1 The average driving cycle in the suburban BMR, based on the tests along the 3 traffic routes selected for this study, was compared with the Bangkok driving cycle

	For obtained driving cycle	For Bangkok driving cycle
V_{max}	97.50 km/h	80.1 km/h
V_{min}	0 km/h	0 km/h
$V_{average}$	40.05 km/h	11.4 km/h
distance	17.62 km	6.1 km
duration	0.44 hr (1,585 s)	1.035 hr (3,726 s)

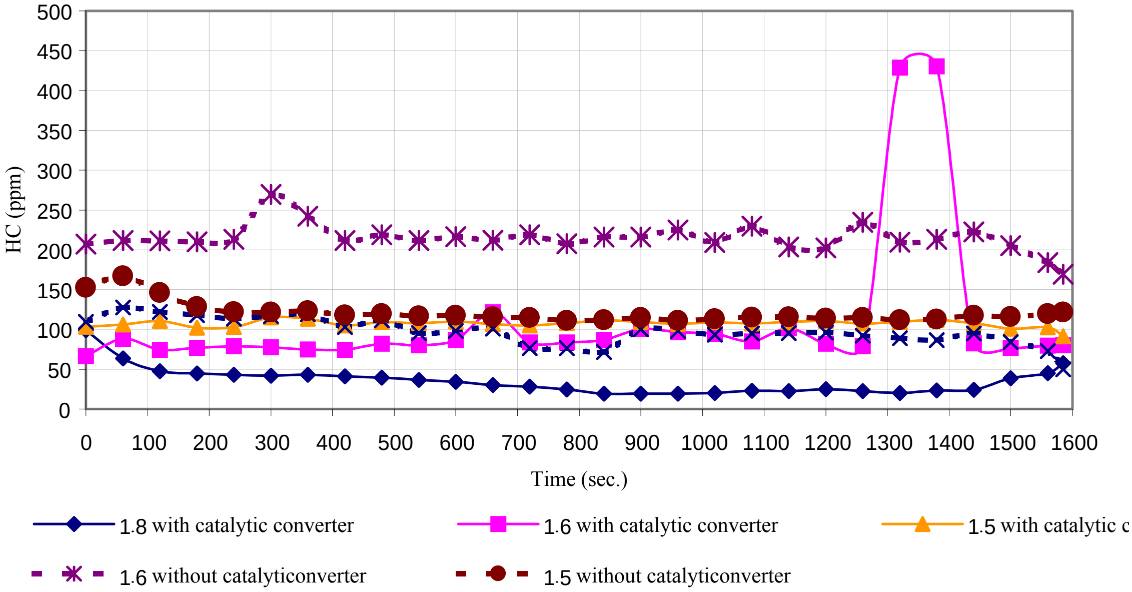

Figure 4.12 HC Concentrations in the exhaust emission of the test cars during simulation runs

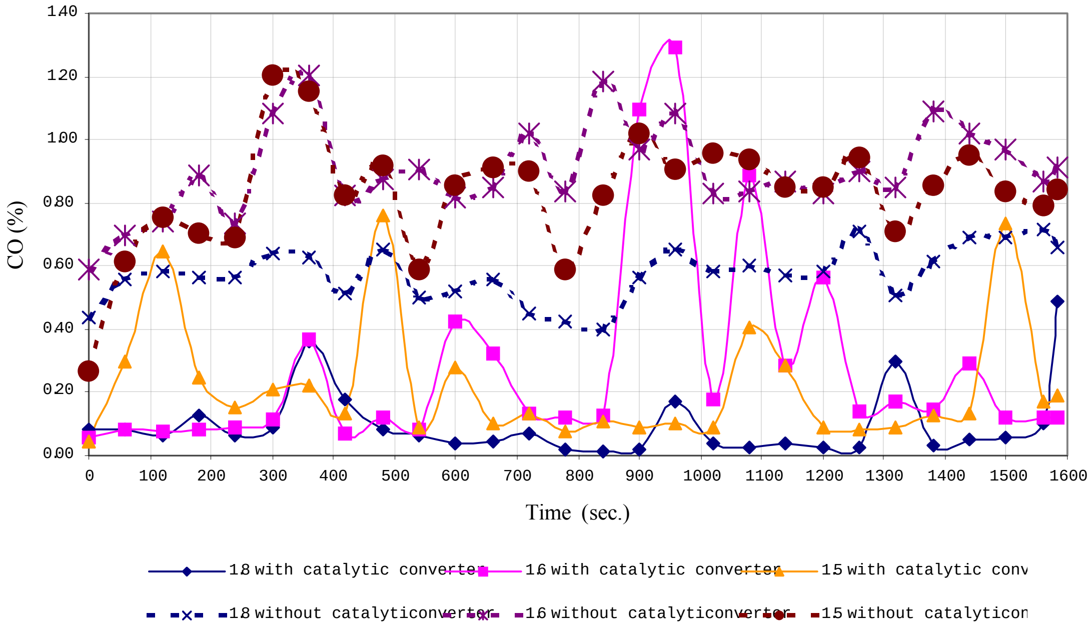

Figure 4.13 CO Concentrations in the exhaust emission of the test cars during simulation runs

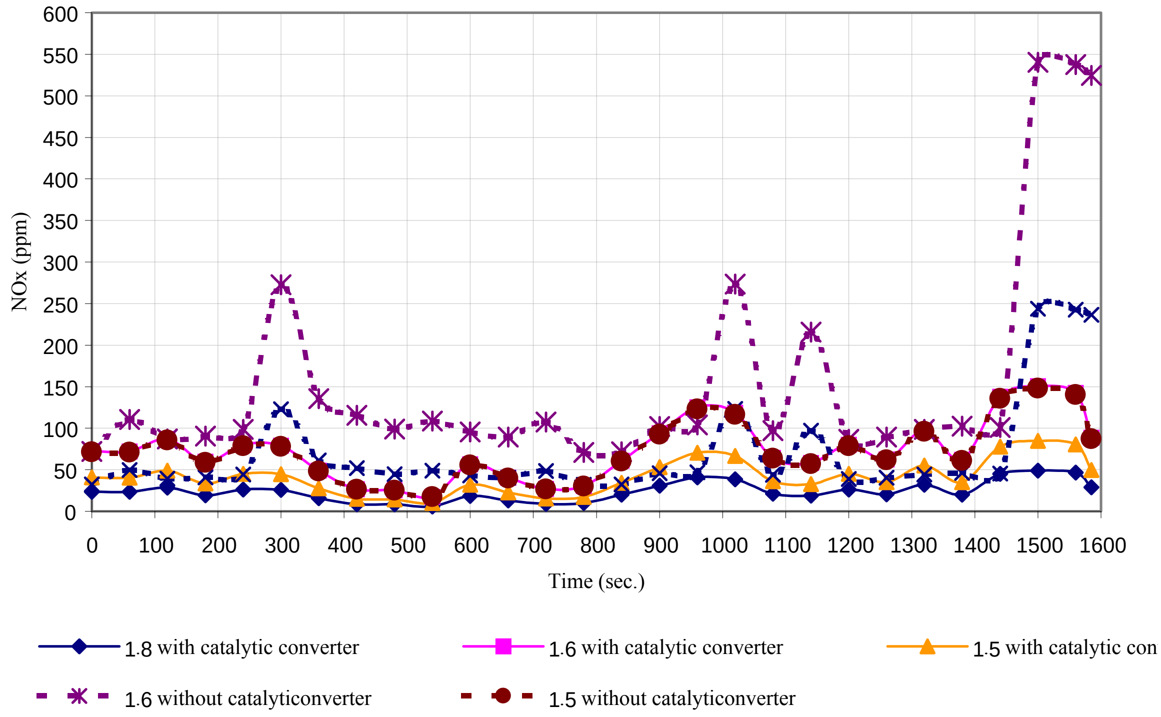

Figure 4.14 NO_x Concentrations in the exhaust emission of the test cars during simulation runs

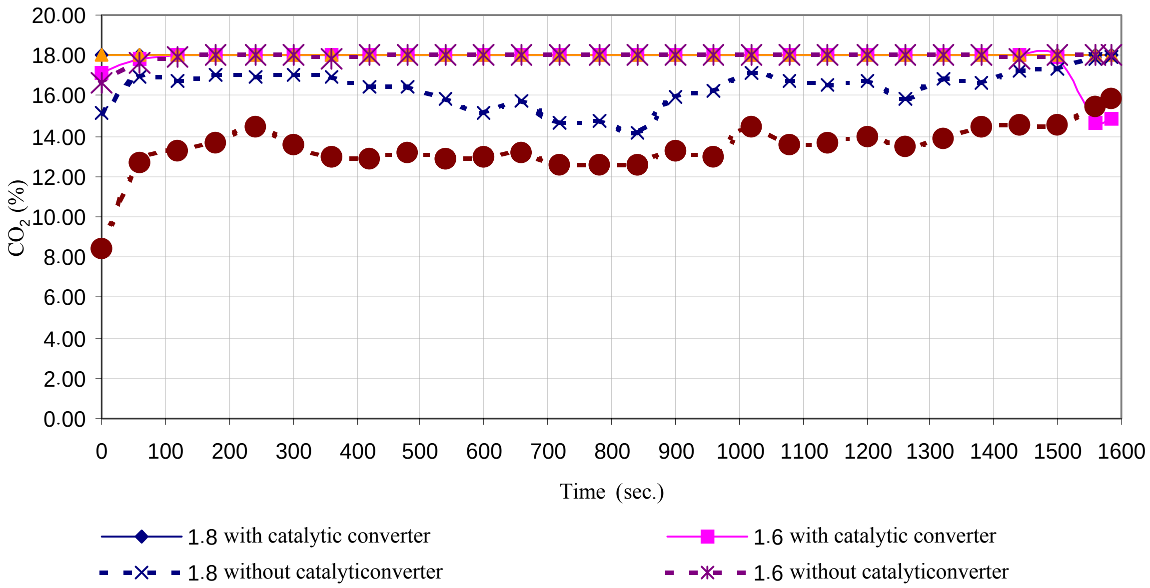

Figure 4.15 CO_2 Concentrations in the exhaust emission of the test cars during simulation runs

4.2 Exhaust Emission Measurements

4.2.1 Chassis Dynamometer Simulation Tests

The exhaust emission tests were conducted using obtained driving cycle with the 3 test cars on the chassis dynamometer in a laboratory at the Mitsubishi Motor Corporation Sittipol Co.,Ltd. in Klong Luang district of Pathumthani Province of Thailand.

The average concentrations of the various measured parameters in the exhaust gases of the test cars during the simulation tests are shown in Figures 4.12-4.15 and in Table B.1-B.18.

Comparative results of the pollutants emitted from the 3 test cars equipped with and without three-way catalytic converter are summarized in Table 4.2-4.4. The pollutants after using three-way catalytic converter were lower than before using.

The average concentrations of the various measured parameters in the exhaust gases of the test cars during the simulation tests and compare with Emission Standards for In-Use Motor Vehicles in Thailand (Gasoline Vehicle) are shown in Tables 4.5-4.6.

The average value of total particulate matter (TPM) measurement for 3 test passenger cars are given in Table 4.7. The TPM concentration from 1.5 L Mitsubishi Lancer were higher than 1.6 L and 1.8 L Mitsubishi Lancer for both with and without three-way catalytic converter.

Table 4.2 Average concentration of pollutants from1.5 L Mitsubishi Lancer equipped with and without 3-way catalytic converter

Pollutants	Without 3-way catalytic converter	With3-way catalytic converter	% change
HC (ppm)	120.77	107.20	11.2
CO(%)	0.83	0.22	73.5
NO_X (ppm)	72.50	41.57	42.6
CO_2	13.43	18.00	-34.03
TPM(mg/f.paper)	8.5	7.7	9.4

Table 4.3 Average concentration of pollutants from1.6 L Mitsubishi Lancer equipped with and without 3-way catalytic converter

Pollutants	Without 3-way catalytic converter	With3-way catalytic converter	% change
HC (ppm)	214.30	109.07	49.1
CO(%)	0.90	0.27	70
NO_X (ppm)	160.61	73.77	54.1
CO_2	17.92	17.73	1.1
TPM(mg/f.paper)	8.1	4.5	44.4

Table 4.4 Average concentration of pollutants from1.8 L Mitsubishi Lancer equipped with and without 3-way catalytic converter

Pollutants	Without 3-way catalytic converter	With3-way catalytic converter	% change
HC (ppm)	96.68	35.57	63.2
CO(%)	0.58	0.10	82.8
NO_X (ppm)	72.45	24.06	66.8
CO_2	16.38	18.00	-9.9
TPM(mg/f.paper)	9.1	5.1	44

Table 4.5 Average concentrations of the various measured parameters in the exhaust gases of the test cars during the simulation tests

	With Three-way Catalytic Converter					Without Three-way Catalytic Converter				
	HC (ppm)	CO (%)	NO_x (ppm)	CO_2 (%)	TPM (mg/f.paper)	HC (ppm)	CO (%)	NO_x (ppm)	CO_2 (%)	TPM (mg/f.paper)
l. Lancer 1.5	107.20	0.22	41.57	18.00	7.7	120.77	0.83	72.50	13.43	8.5
2.Lancer 1.6	109.07	0.27	73.77	17.73	4.5	214.30	0.90	160.61	17.92	8.1
3.Lancer 1.8	35.57	0.10	24.06	18.00	5.151	96.68	0.58	72.45	16.38	9.1

Table 4.6 Average concentrations of the various measured parameters in the exhaust gases of the test cars during the simulation tests compare with Emission Standards for In-Use Motor Vehicles in Thailand (Gasoline Vehicle)

	With Three-way Catalytic Converter					Without Three-way Catalytic Converter				
	HC (ppm)	CO (%)	NO_x (ppm)	CO_2 (%)	TPM (g/f.paper)	HC (ppm)	CO (%)	NO_x (ppm)	CO_2 (%)	TPM (g/f.paper)
l. Lancer 1.5	107.20	0.22	41.57	18.00	0.0077	120.77	0.83	72.50	13.43	0.0085
2.Lancer 1.6	109.07	0.27	73.77	17.73	0.0045	214.30	0.90	160.61	17.92	0.0081
3.Lancer 1.8	35.57	0.10	24.06	18.00	0.0051	96.68	0.58	72.45	16.38	0.0091
Emission Standards										
Car Register before November, 1993	-	-	-	-	-	600	4.5	-	-	-
-Car Register after November, 1993	200	1.5	-	-	-	-	-	-	-	-

Table 4.7 Total particulate matter measurement for 3 test passenger cars at 5,500 rpm acceleration for 1-2 seconds

No.	Passenger Car	1st Measurement (mg/s)	2nd Measurement (mg/s)	3rd Measurement (mg/s)	Average value (mg/s)
1.	1.5 L Lancer with catalytic converter	4.600	1.300	2.100	2.668
2.	1.5 L Lancer without catalytic converter	8.200	8.300	2.600	6.366
3.	1.6 L Lancer with catalytic converter	1.200	0.700	8.300	3.400
4.	1.6 L Lancer without catalytic converter	0.500	9.000	0.900	3.466
5.	1.8 L Lancer with catalytic converter	1.400	1.500	1.900	1.600
6.	1.8 L Lancer without catalytic converter	2.000	5.600	3.000	3.533

Remarks:

1. Measurements were made by accelerating the engine and passing the exhaust through the filter paper for 1-2 seconds.
2. Weighing the filter paper before and after exhaust sampling in the air conditioned lab by using digital weight measurement.

The results of total particulate matter measurement for 3 test cars, while the engine were accelerated to 3,000 rpm for 10 seconds, are shown in Table 4.8 below:

Table 4.8 Total particulate matter measurement for 3 test passenger cars at 3,000 rpm acceleration in 10 seconds

No.	Passenger Car	1st Measurement (mg/s)	2nd Measurement (mg/s)	3rd Measurement (mg/s)	Average value (mg/s)
1.	Lancer 1.5 with catalytic converter	0.6	0.29	0.14	0.77
2.	Lancer 1.5 without catalytic converter	0.73	0.81	1.02	0.85
3.	Lancer 1.6 with catalytic converter	0.51	0.47	0.39	0.46
4.	Lancer 1.6 without catalytic converter	0.87	0.63	0.92	0.81
5.	Lancer 1.8 with catalytic converter	0.32	1.00	0.21	0.51
6.	Lancer 1.8 without catalytic converter	0.91	0.85	0.98	0.91

Table 4.9 Thai Industrial Standards Institute (TISI) For Emission Emitted From Vehicle

			Limit Value (g/km.)				
Category	Class	Reference Mass (kg)	CO		THC+NOx		PM
			Petrol	Diesel	Petrol	Diesel	Diesel
M	-	All	2.2	1.0	0.5	0.7	0.08
N1	I	RW< 1,250	2.2	1.0	0.5	0.7	0.08
	II	1250< RW < 1,700	4.0	1.25	0.6	1.0	0.12
	III	1,700< RW	5.0	1.5	0.7	1.2	0.17

4.3 Model Calculation

4.3.1 Estimation of Number of Vehicles and Vehicle Kilometer Traveled

Table 4.10 presents the number of cars plying on the roads of Bangkok Metropolitan Region for the years 1996, 1997, 1998, 1999, 2000, and, 2001. The figures in the table were estimated based on the information provided by different agencied located in the Bangkok Metropolitan Region, such as Land Transport Department.

Table 4.10 Vehicle types and their numbers in Bangkok Metropolitan Region (BMR)

Type of Vehicle	Year					
	1996	1997	1998	1999	2000	2001
Passenger Car Units (PCUs)	1,090,826	1,218,058	1,298,582	1,388,873	1,315,043	1,400,713

Note From Land Transport Department (2002) Appendix C Table C.1-C.6

Table 4.11 Average distance traveled per year by the 3 test cars

Engine Sizes	Mileage (km)	Model Year	Distance travel/year (km)
1.5 L	80,812	1996	13,468.67
1.6 L	67,000	1999	22,333.33
1.8 L	23,465	2000	11,732.5

The average distance traveled per year (km/year-unit), fuel efficiency (km/L), and average annual fuel consumption (L/year-unit) of the passenger cars in Bangkok Metropolitan Region (BMR) were obtained by surveying the sampling of 100 cars in BMR. The results are shown in Table 4.12 below. Table 4.13 shows the average exhaust emission factors for cars at average speed 24km/h.

Table 4.12 Estimated average distance traveled per year (km/year-unit), fuel efficiency (km/L), and average annual fuel consumption (L/year-unit) in Bangkok Metropolitan Region (BMR)

Vehicle type	$Vk_{mi(t)}$ Average traveled (km/yr-unit)	$FE_i(t)$ Fuel efficiency (km/L)	$F_i(t)$ Average fuel consumption (L/Yr-unit)
Car	19,520.67	10.85	1,799.97

Note From the study (100 cars sampling in BMR 2002)

Table 4.13 Average exhaust emission factors for cars at average speed 24km/h

Vehicle type	Fuel type	CO (g/km)	HC (g/km)	NO_2 (g/km)	SO_2 (g/km)	TSP (g/km)	PM_{10} (g/km)
Car	Gasoline	62	8.30	2.35	0.315	0.20	2.80

Note From Vitoonchavaritvong (1993) and Shrestha and Malla (1996)

In order to use equation 3.1 and 3.2, values of various terms determined are shown as below :

$N_i(t)$ = Number of vehicles in operation by vehicle type "i" " in year "t"
= 1,400,713 in year 2001

$F_i(t)$ = Average fuel consumption by vehicle type "i" in year "t" (L)
= 1,799.97 in year 2001

$FE_i(t)$ = Fuel efficiency of vehicle type "i" in year "t" (km/L)
= 10.85 in year 2001

EF_{ik} = Exhaust emission factor expressed as the mass of pollutant per unit of distance traveled (g/km) are taken from Table 4.13.

$Vkm_i(t)$, the average vehicle-kilometer traveled for passenger cars in year "t". = 19,520.67 in year 2001. Exhaust emission by vehicle type "i" for pollutant type "j" in year "t", (tonne):

$M_{ij}(t) = N_i(t)\ vkm_i(t)\ EF_{ik}$

$M_{ij}(t) = 1{,}400{,}713 \times 19{,}520.67 \times EF_{ik}$

EF_{ik} = Exhaust emission factors expressed as the mass of pollutant per unit of distance traveled (g/km) for 6 pollutants in exhaust gases of passenger cars in BMR are used from table 4.31

4.3.2 Exhaust emission estimation of pollutants during the period (1996-2001)

Using the information from Table 4.13 and the data calculated from equations (3.1) and (3.2) the estimated exhaust emissions of the five major air pollutants from passenger cars in BMR during 1996-2001 are shown in Table 4.14.

4.3.3 Estimation of the growth rate and number of cars in Bangkok Metropolitan Region (BMR) in next 5 years

Table 4.15 presents the estimated number of passenger cars plying on the roads of Bangkok Metropolitan Region during the next 5 years. In order to obtain the forecasted number of passenger cars in BMR during 2002-2006, following equation was used :

$V_p = V_b(1+g_r)^{nt}$

V_p = Number of cars in year "t"

V_b = Number of cars in base year

Table 4.14 Estimated exhaust emissions of the five major air pollutants from passenger cars in BMR during 1996-2001

Year	$M_{ij}(t)$					
	CO (tonne)	SO_2 (tonne)	NO_2 (tonne)	HC (tonne)	TSP (tonne)	Total (tonne)
1996	1,320,206.57	10,646.83	42,587.31	176,737.33	4,258.73	1,554,436.77
1997	1,474,193.11	11,888.65	47,554.62	197,351.66	4,755.46	1,735,743.50
1998	1,571,649.82	12,674.60	50,698.38	210,398.28	5,069.84	1,850,490.92
1999	1,680,927.35	13,555.87	54,223.46	225,027.37	5,422.35	1,979,156.40
2000	1,591,572.27	12,835.26	51,341.04	213,065.32	5,134.10	1,863,947.99
2001	1,695,257.09	13,671.43	54,685.71	226,945.71	5,468.57	1,996,028.51

N_t = Number of year "t"

g_r = Compound growth rate of cars

From Table 4.10

V_b = Number of cars in base year (1996) = 1,090,826

V_p = Number of cars in year "t" (2001) = 1,400,713

$V_p = V_b(1+g_r)^{nt}$

$1{,}400{,}713 = 1{,}090{,}826\,(1+g_r)^5$

$g_r = 0.05126$

Therefore, number of cars in 2002

$V_{p2002} = 1{,}090{,}826(1+0.05126)^6 = 1{,}472{,}367.833$

Number of cars in 2003

$V_{p2003} = 1{,}090{,}826(1+0.05126)^7 = 1{,}547{,}841.409$

Number of cars in 2004

$V_{p2003} = 1{,}090{,}826(1+0.05126)^8 = 1{,}627{,}183.759$

Number of cars in 2005

$V_{p2003} = 1{,}090{,}826(1+0.05126)^9 = 1{,}710{,}593.199$

Number of cars in 2006

$$V_{p2003} = 1{,}090{,}826(1+0.05126)^{10} = 1{,}798{,}278.206$$

Table 4.15 Estimated numbers of cars in Bangkok Metropolitan Region (BMR) in 5 years

Type of Vehicle	Year				
	2002	2003	2004	2005	2006
Car	1,472,367.833	1,547,841.409	1,627,183.759	1,710,593.199	1,798,278.206

4.3.4 Future emission estimation (2002-2006)

Using the information from Table 4.15 and equation (3.1) and (3.2) estimated exhaust emissions of the five major air pollutants from passenger cars in BMR during 2002-2006 are given in Table 4.16.

Table 4.16 Estimated exhaust emissions of the five major air pollutants from passenger cars in BMR during 2002-2006

Year	$M_{ij}(t)$					
	CO tonne	SO_2 tonne	NO_2 tonne	HC tonne	TSP tonne	Total tonne
2002	1,781,979.81	14,370.80	57,483.22	238,555.36	5,748.32	2,098,137.51
2003	1,873,324.60	15,107.46	60,429.83	250,783.78	6,042.98	2,205,688.65
2004	1,969,350.76	15,881.86	63,527.44	263,638.89	6,352.74	2,318,751.69
2005	2,070,299.13	16,695.96	66,783.84	277,152.95	6,678.38	2,437,610.26
2006	2,176,422.67	17,551.80	70,207.18	291,359.81	7,020.72	2,562,562.18

4.4 Thailand's Automotive Air Pollution Control Strategies

The public and the government are voicing their serious concern about the increasing trend of environmental pollution problems. The previous Seventh (1992-1996) and the current Eighth Five-year National Economic and Social Plan (1997-2001) have moved towards a sustainable economic growth and promoted development while enhancing the quality of the environment and natural resource base so as the new Institution promulgated in 1997.

To achieve the targets, a concerted cooperative effort is being made by the government, industries, the public, and non-governmental organizations to restore the quality of the air in Bangkok. A number of measures have been adopted to mitigate air pollution problems, particularly those caused by the transport sector. They are aimed not only at exhaust gas emission controls but also at the improvement of fuel quality and engine specification, implementation of in-use vehicle inspection and maintenance program, public transport improvement through mass transit systems, and the improvement of traffic condition through better traffic management.

Among others, specific measures directed toward reducing vehicle emissions include:

1. Improvement of Fuel Quality
2. Emission Standards for New Vehicles
3. Emission Standards for In-use Vehicles
4. Inspection and Maintenance Program
5. Roadside Inspection
6. Traffic Management and VKT Reduction
7. Other Measures

Roadside Inspection

Roadside inspection for smoky vehicles in Bangkok is carried out every day by four agencies, i.e. Police Department, Land Transport Department, Department of Pollution Control, and Bangkok Metropolitan Administration. Drivers of vehicles violating emission standards for in-use vehicles will be fined and vehicles will not be allowed to be used on the street until they are repaired and pass the reinspection. Currently, there are up to 30 to 40 inspecting teams doing roadside inspection every day.

Emission Standards for In-use Vehicles

Emission standards for in-use vehicles are used mainly as reference standards for the inspection and maintenance program which includes periodical inspection and roadside inspection. The standards were revised to be more stringent taking into account emission standards for new vehicles and have just been promulgated at the beginning of 1998.

Traffic Management and Vehicle Kilometers Traveled (VKT) Reduction

The Office of the Commission for the Management of Land Traffic under the Prime Minister Office is doing every possible way to reduce traffic congestion in order to increase traffic speed in Bangkok and reduce vehicle kilometers traveled (VKT). Some of the measures implemented are as follows,

- Two mass rapid transit systems, i.e. an elevated sky train system and a subway system, are under construction. The elevated sky train system will be in operation in 1999 while the subway system will be in operation in the year 2002.
- Bus system reform.
- Increasing road network and expressway.
- Automatic Computerized Traffic Light Management System.
- Parking restriction on major streets.
- Flexible working hours.
- Strict enforcement of traffic regulation.
- Bus lane.
- Reversible lane.

Restricting the use of private vehicles during rush hours based on the license plate number is being discussed. Vehicles will not be allowed to be used during rush hours on the date having the same last digit as the license plate numbers of the vehicles. For example, if the last digit of the license plate number is 1, the vehicle will not be allowed to be used on the first, the eleventh, the twenty first, and thirty first of every month. This means that traffic volume will be reduced by 10% and each vehicle will not be allowed to be used only 3 to 4 days a month compared to 15 days if odd and even numbers are used. (Source: http.//www.pcd.go.th)

Chapter V
Conclusions and Recommendations

5.1 Conclusions

Based on the results of this study, following conclusions could be made;

1. Emission measurement using three obtain driving cycles on chassis dynamometer shows that all concentrations of exhaust gas from non-catalytic converter cars are higher than catalytic converter car, except carbon dioxide. Because of catalytic converter changed carbon monoxide to carbon dioxide.

2. Emission Measurement on chassis dynamometer with the obtained driving cycle shows that concentration of exhaust gas from non-catalytic converter cars are higher than catalytic converter car, Carbon monoxide (CO), hydrocarbon (HC), and Nitrogen oxides (NO_X) emissions from 3 test cars without three-way catalytic converter are higher than 3 test cars with three-way catalytic converter.

3. Passenger cars take in account of 46-49 percent of total vehicle travel on the road in Bangkok between 1996-2001.(From Table C.1-C.6) It is approximately half of total vehicle on the road and it significantly produces pollutants to the ambient air.

4. The road which has high traffic volume, has high pollutants concentration. The 3 selected routes from this experiment were difference in traffic condition depended on the time morning, afternoon, and evening.

5. Catalytic converter may help in improving roadside air quality by transforming HC, CO and NO_X into harmless CO_2, H_2O, N_2, and O_2.

6. As the catalytic reaction take place, normal internal temperature of the catalytic converter rise to somewhat between 400 to 700 °C (750 to 1300 °F), while normal outer surface heat generally reaches around 150 to 300°C (300 to 570 °F).

7. If the engine is in poor operating condition, is operating under a severe load, is in need of a tuned-up or has several misfiring cylinders, higher temperatures than normal are easily reached, both inside and outside the converter shell.

8. Excessively high temperatures reduce converter life and can destroy the cores of the catalytic converter.

5.2 Recommendations for Future Work

1. To obtain driving cycles on several traffic routes with various cars of different makes, models, and mileage.

2. To conduct the simulation test runs and measure the pollutants in exhaust emissions from the various types of cars.

3. To find out the correlation between the exhaust emissions' concentrations and the ambient air quality.

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Appendix A

Average driving cycle

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
23	110	81.33	54.17	44.33	63.83	53.17	44.83	75.83	26.33	36.83	53.41
24	115	81.33	51.00	43.83	65.67	49.33	50.33	77.00	24.67	32.33	52.83
25	120	82.67	48.17	46.83	64.83	48.33	56.50	76.83	20.83	27.83	52.54
26	125	79.67	48.67	49.50	64.17	48.83	56.50	76.50	16.17	19.67	51.07
27	130	80.33	44.67	51.83	64.33	48.00	60.17	75.67	14.83	19.50	51.04
28	135	80.00	42.00	50.17	64.00	50.50	63.00	77.17	14.83	19.33	51.22
29	140	82.50	45.00	53.33	64.33	54.17	65.17	80.50	20.33	15.17	53.39
30	145	85.00	43.67	54.17	68.67	48.67	67.83	82.67	29.17	18.00	55.31
31	150	86.83	46.50	53.33	72.17	43.50	66.67	86.17	33.83	23.33	56.93
32	155	87.83	44.67	51.00	76.50	37.00	63.00	84.17	38.33	23.67	56.24
33	160	87.67	36.17	45.17	77.83	23.33	62.67	83.17	32.67	28.50	53.02
34	165	86.00	39.67	44.33	80.83	34.00	64.00	82.17	37.67	32.33	55.67
35	170	85.50	38.50	41.00	80.67	38.67	63.50	80.00	41.17	29.00	55.33
36	175	87.67	39.00	35.00	80.33	32.67	65.67	79.00	39.33	25.67	53.81
37	180	87.67	44.17	37.00	78.50	32.33	65.67	77.00	41.33	27.17	54.54
38	185	88.83	45.83	37.83	76.17	20.50	68.83	75.17	41.83	28.00	53.67
39	190	88.67	46.17	38.67	74.83	22.50	70.00	73.67	41.00	30.00	53.94
40	195	87.17	24.33	39.67	74.83	24.67	62.33	72.33	44.00	30.83	51.13
41	200	90.00	23.00	42.00	77.00	27.00	54.83	72.33	45.67	31.67	51.50
42	205	88.83	29.17	43.83	78.17	28.83	51.00	78.00	47.33	29.17	52.70
43	210	87.00	34.33	43.00	77.67	24.67	51.83	80.67	46.33	26.17	52.41
44	215	85.17	20.67	43.83	80.17	28.50	51.33	81.83	32.17	25.33	49.89
45	220	85.83	14.67	41.33	75.50	29.83	53.33	84.50	29.67	25.33	48.89
46	225	89.17	12.17	34.00	77.00	38.33	55.83	87.83	31.83	26.33	50.28

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
47	230	92.67	11.50	31.00	75.50	41.67	54.00	92.50	31.67	33.17	51.52
48	235	95.17	22.67	34.00	75.50	43.50	49.83	93.50	26.00	38.17	53.15
49	240	94.17	12.17	40.67	77.33	51.67	45.17	94.67	24.33	38.67	53.20
50	245	92.17	12.33	43.17	75.83	47.17	43.00	90.50	19.67	40.00	51.54
51	250	92.83	18.33	48.00	73.33	48.83	40.17	91.00	17.67	38.00	52.02
52	255	94.17	24.50	46.83	71.17	51.67	36.50	92.67	8.33	41.50	51.93
53	260	91.00	23.33	44.17	67.17	43.67	33.33	93.67	7.33	38.83	49.17
54	265	78.00	25.67	39.00	68.83	42.83	27.33	90.67	16.00	33.67	46.89
55	270	63.83	28.00	36.33	64.17	39.17	26.17	86.67	11.83	36.33	43.61
56	275	59.33	32.67	29.83	66.83	30.67	26.00	85.33	19.83	43.00	43.72
57	280	53.33	32.83	34.83	69.50	27.50	25.17	85.33	23.33	43.83	43.96
58	285	47.67	36.67	27.67	66.17	28.17	20.50	80.67	26.33	41.50	41.70
59	290	47.67	34.00	30.17	67.17	30.67	16.80	75.83	28.00	39.17	41.05
60	295	47.17	31.50	27.00	62.83	40.33	24.20	66.17	24.33	34.17	39.74
61	300	48.00	39.00	29.67	65.67	48.33	24.60	66.67	35.67	29.50	43.01
62	305	49.00	38.33	28.50	62.83	49.67	26.80	68.67	41.00	26.00	43.42
63	310	50.83	41.83	30.33	60.67	54.00	29.00	67.00	43.00	22.00	44.30
64	315	50.17	41.33	28.00	59.33	44.67	33.00	62.83	43.00	22.33	42.74
65	320	53.33	46.33	31.17	62.17	46.17	36.40	61.50	42.00	24.67	44.86
66	325	54.50	47.33	34.50	60.33	43.00	26.50	67.67	40.00	28.33	44.69
67	330	55.50	46.17	33.17	60.67	41.33	29.25	70.17	33.67	27.50	44.16
68	335	52.67	42.33	34.67	61.67	41.17	28.50	74.67	21.33	26.33	42.59
69	340	53.33	41.67	36.67	59.33	35.50	21.00	76.17	17.33	25.67	40.74
70	345	52.00	41.67	39.67	58.83	33.33	4.67	76.17	11.67	20.20	37.58

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
71	350	44.83	35.00	38.33	58.83	23.33	7.67	74.33	15.83	17.40	35.06
72	355	44.33	31.00	39.33	58.00	19.50	18.67	73.17	17.17	15.60	35.20
73	360	38.17	32.00	31.00	61.17	18.67	20.67	71.67	21.67	14.40	34.38
74	365	43.83	29.67	23.00	62.33	20.50	15.00	72.83	21.00	7.80	32.89
75	370	46.17	29.50	24.50	62.83	30.50	4.67	69.83	17.50	2.80	32.03
76	375	34.83	29.50	17.50	66.67	31.67	-	53.17	22.33	1.20	28.54
77	380	29.00	35.33	9.25	69.00	35.17	-	49.17	32.00	0.60	28.84
78	385	30.25	41.50	8.50	71.33	32.17	-	49.17	37.50	-	30.05
79	390	26.75	46.33	12.50	74.80	33.50	-	52.00	41.17	-	31.89
80	395	24.75	51.83	9.25	69.00	35.67	9.33	52.33	47.67	-	33.31
81	400	11.25	50.17	11.25	63.20	31.00	15.67	52.17	49.00	4.00	31.97
82	405	18.67	50.17	11.25	56.80	26.50	4.67	51.60	41.33	10.60	30.18
83	410	19.00	47.67	9.00	47.00	26.67	3.00	51.00	29.00	13.40	27.30
84	415	25.33	27.50	8.50	50.00	25.33	4.00	37.00	28.00	12.80	24.27
85	420	26.33	12.17	8.50	52.60	23.33	2.00	32.67	23.33	12.40	21.48
86	425	21.33	8.33	9.00	50.40	19.83	3.67	43.33	21.33	14.60	21.31
87	430	20.33	8.83	8.50	44.80	19.33	3.67	41.67	27.67	16.20	21.22
88	435	24.33	16.83	12.00	35.80	14.00	5.67	23.00	34.67	18.60	20.54
89	440	30.00	18.50	14.75	56.33	18.50	9.33	53.00	39.17	18.00	28.62
90	445	30.67	22.00	17.50	57.00	25.33	5.67	62.00	42.17	14.00	30.70
91	450	33.00	22.00	20.25	53.00	30.00	-	64.00	38.67	14.60	30.61
92	455	36.00	24.17	12.00	31.00	31.17	-	67.00	32.50	18.00	27.98
93	460	34.33	31.17	-	29.00	32.67	-	56.00	28.33	20.20	25.74
94	465	36.67	35.50	-	59.00	33.17	2.67	53.00	38.33	21.40	31.08

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
95	470	36.67	37.33	-	62.00	35.17	6.67	50.00	38.33	24.60	32.31
96	475	31.67	40.50	6.67	64.00	40.50	4.67	50.00	35.33	25.80	33.24
97	480	41.33	42.33	10.33	70.00	43.83	4.67	42.00	37.33	28.00	35.54
98	485	38.67	40.00	14.00	67.00	38.17	8.33	34.00	40.00	29.80	34.44
99	490	30.67	35.17	21.00	50.00	36.67	-	14.00	34.33	15.25	26.34
100	495	34.67	39.00	14.00	36.00	40.83	-	17.00	31.67	14.00	25.24
101	500	41.67	29.50	11.00	22.00	41.50	6.67	28.00	28.00	14.00	24.70
102	505	39.33	36.83	14.00	3.00	44.33	5.67	36.00	28.00	14.00	24.57
103	510	35.33	46.33	14.00	-	43.83	3.67	39.00	28.33	16.00	25.17
104	515	41.00	46.67	15.50	-	42.83	2.00	22.00	26.33	15.50	23.54
105	520	43.00	50.83	7.00	-	30.00	3.67	17.00	26.67	13.25	21.27
106	525	46.67	51.67	9.50	-	29.00	-	17.00	29.33	9.75	21.44
107	530	39.33	51.17	5.50	-	30.83	-	31.00	29.00	7.75	21.62
108	535	41.33	54.67	-	-	33.50	4.67	36.00	26.33	10.50	23.00
109	540	39.33	56.00	-	-	29.83	4.67	36.00	23.33	14.00	22.57
110	545	42.00	49.17	-	-	29.33	6.33	39.00	22.33	13.25	22.38
111	550	47.33	48.17	7.00	-	30.83	2.67	48.00	19.67	11.25	23.88
112	555	45.33	48.00	12.50	-	37.00	3.67	50.00	17.67	7.75	24.66
113	560	47.00	53.33	3.00	-	44.50	5.67	45.00	18.67	7.75	24.99
114	565	36.33	55.83	6.00	-	51.00	13.00	36.00	18.67	9.00	25.09
115	570	34.67	59.67	-	-	54.33	29.00	22.00	14.00	11.25	24.99
116	575	38.33	64.33	-	-	56.33	33.50		9.33	14.00	26.98
117	580	39.67	67.17	-	-	51.00	18.00		4.67	14.75	24.41
118	585	29.33	67.67	-	-	53.67	18.00		1.00	16.25	23.24

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
119	590	23.00	71.17	-	8.00	50.33	19.50		2.67	12.00	23.33
120	595		77.50	-	25.00	59.33	17.00		9.33	13.50	28.81
121	600		75.00	-	34.00	64.17	21.00		11.33	8.50	30.57
122	605		60.33	-	31.00	66.00	18.50		17.00	12.50	29.33
123	610		51.00	-	36.00	56.83	18.00		25.00	12.50	28.48
124	615		58.00	8.50	50.00	47.67	17.00		34.33	13.25	32.68
125	620		59.00	8.50	56.00	35.67	15.50		37.33	11.25	31.89
126	625		64.83	15.50	56.00	19.00	5.50		40.00	5.75	29.51
127	630		67.67	11.00	53.00	25.33	8.50		43.00	12.00	31.50
128	635		67.50	10.00	53.00	25.17	1.50		45.67	13.50	30.90
129	640		68.17	12.50	62.00	25.33	-		46.00	14.00	32.57
130	645		75.67	3.00	64.00	25.83	3.00		46.67	8.50	32.38
131	650		75.67	1.50	64.00	28.83	1.50		48.33	7.00	32.40
132	655		81.67	1.50	62.00	31.33	4.00		47.67	10.50	34.10
133	660		80.17	4.00	53.00	21.17	11.00		44.67	9.00	31.86
134	665		82.17	1.50	59.00	21.00	8.50		57.67	11.25	34.44
135	670		80.17	-	50.00	27.00	3.00		62.67	7.00	32.83
136	675		65.00	-	25.00	28.67	-		55.00	3.50	25.31
137	680		54.50	-	8.00	28.17	-		50.33	2.75	20.54
138	685		63.67	1.50	-	22.33	-		51.33	3.50	20.33
139	690		64.33	-	-	18.67	-		51.33	4.25	19.80
140	695		65.67	-	-	19.00	-		54.33	3.50	20.36
141	700		56.33	-	-	19.67	-		54.33	3.50	19.12
142	705		58.33	-	-	19.00	4.00		45.67	12.00	19.86

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
143	710		64.67	-	-	26.33	1.50		43.67	8.50	20.67
144	715		64.00	-	-	27.00	-		38.33	9.00	19.76
145	720		61.67	-	-	34.50	7.00		35.33	9.75	21.18
146	725		48.17	-	-	40.33	3.00		31.67	7.75	18.70
147	730		51.00	-	-	46.00	-		22.33	5.00	17.76
148	735		45.67	-	-	47.50	-		21.33	7.50	17.43
149	740		47.17	-	-	47.33	-		23.33	10.50	18.33
150	745		51.33	-	-	43.50	4.00		24.33	4.25	18.20
151	750		50.00	7.00	-	39.17	3.00		28.00	4.25	18.77
152	755		52.33	8.50	-	41.50	-		29.00	6.25	19.65
153	760		55.33	5.50	-	45.00	-		21.33	9.75	19.56
154	765		53.50	-	-	45.17	1.50		12.00	13.50	17.95
155	770		51.17	-	-	36.50	3.00		13.00	16.75	17.20
156	775		48.67	-	-	24.83	3.00		16.00	21.00	16.21
157	780		42.00	-	-	20.17	3.00		19.67	19.00	14.83
158	785		44.00	-	-	16.17	12.50		7.33	13.50	13.36
159	790		42.50	-	-	16.33	25.50		8.33	18.75	15.92
160	795		29.17	-	-	17.67	19.50		16.00	20.50	14.69
161	800		31.33	-	-	11.67	17.00		17.67	23.00	14.38
162	805		37.00	-	-	10.17	8.00		23.33	28.25	15.25
163	810		35.00	-	-	19.33	11.00		31.00	32.25	18.37
164	815		37.00	-	-	18.17	20.00		33.67	28.00	19.55
165	820		45.17	-	-	9.83	22.00		36.33	13.00	18.05
166	825		44.33	-	-	10.83	8.00		38.33	5.67	15.31

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
167	830		38.33	-	-	5.67	3.00		38.33	3.67	12.71
168	835		37.33	-	-	4.67	-		36.33	1.00	11.33
169	840		42.33	-	-	8.67	-		34.67	4.67	12.90
170	845		42.17	-	-	9.83	11.00		26.00	10.33	14.19
171	850		54.83	-	17.00	15.33	3.00		29.00	13.00	18.88
172	855		63.33	-	34.00	20.17	-		24.67	12.00	22.02
173	860		67.67	3.00	48.00	25.67	3.00		33.67	11.33	27.48
174	865		61.67	25.00	56.00	28.67	1.00		45.67	13.33	33.05
175	870		61.00	22.00	67.00	30.67	-		55.00	17.00	36.10
176	875		64.17	28.00	73.00	30.67	-		60.00	15.67	38.79
177	880		65.17	42.00	76.00	28.67	-		60.00	8.67	40.07
178	885		66.67	42.00	84.00	34.50	-		62.33	10.33	42.83
179	890		68.00	39.00	90.00	28.33	-		35.00	12.33	38.95
180	895		66.50	48.00	95.00	21.00	-		43.00	4.67	39.74
181	900		63.50	39.00	101.00	22.00	6.00		50.33	2.00	40.55
182	905		69.00	31.00	98.00	27.00	-		55.33	2.00	40.33
183	910		70.50	22.00	95.00	31.00	-		59.67	1.50	39.95
184	915		68.50	11.00	95.00	33.67	-		62.33	3.00	39.07
185	920		63.50	3.00	84.00	36.50	8.00		60.67	-	36.52
186	925		64.00	3.00	78.00	36.67	8.00		58.67	-	35.48
187	930		62.00	-	84.00	38.33	-		62.00	8.50	36.40
188	935		61.00	-	90.00	37.33	-		70.00	7.00	37.90
189	940		62.50	-	76.00	36.83	6.00		74.00	3.00	36.90
190	945		63.00	-	50.00	32.67	14.00		67.67	1.50	32.69

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
191	950		64.50	11.00	31.00	33.17	6.00		60.00	7.00	30.38
192	955		68.67	25.00	31.00	33.17	14.00		50.67	12.50	33.57
193	960		71.17	25.00	62.00	32.33	22.00		60.00	21.00	41.93
194	965		73.17	11.00	76.00	34.50	28.00		69.33	20.00	44.57
195	970		78.17	22.00	84.00	40.17	25.00		74.67	18.00	48.86
196	975		70.40	31.00	78.00	47.50	8.00		74.33	12.50	45.96
197	980		66.60	45.00	73.00	48.17	11.00		76.67	10.00	47.20
198	985		69.80	53.00	73.00	47.17	6.00		79.33	14.00	48.90
199	990		71.60	50.00	73.00	46.00	3.00		77.67	8.50	47.11
200	995		69.20	14.00	70.00	48.83	-		74.67	-	39.53
201	1,000		65.00	3.00	64.00	44.83	3.00		72.67	-	36.07
202	1,005		67.40	22.00	67.00	38.67	20.00		72.67	1.50	41.32
203	1,010		69.40	34.00	70.00	34.00	17.00		76.67	3.00	43.44
204	1,015		67.60	45.00	67.00	31.67	14.00		76.33	5.50	43.87
205	1,020		67.20	39.00	73.00	37.33	-		77.17	1.50	42.17
206	1,025		65.60	31.00	70.00	38.33	-		69.17	1.50	39.37
207	1,030		70.20	31.00	73.00	35.17	6.00		63.50	-	39.84
208	1,035		45.00	34.00	59.00	33.17	-		40.50	4.00	30.81
209	1,040		42.00	45.00	50.00	31.50	-		32.75	14.00	30.75
210	1,045		49.00	28.00	53.00	27.50	3.00		37.50	8.50	29.50
211	1,050		50.50	50.00	56.00	29.00	3.00		43.50	10.00	34.57
212	1,055		49.00	56.00	45.00	27.17	-		43.50	4.00	32.10
213	1,060		49.00	45.00	39.00	29.83	-		42.00	8.50	30.48
214	1,065		50.50	48.00	42.00	32.17	-		43.50	7.00	31.88

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
215	1,070		44.50	50.00	39.00	33.67	-		39.00	3.00	29.88
216	1,075		24.00	45.00	28.00	34.50	-		28.00	1.50	23.00
217	1,080		25.00	31.00	36.00	38.67	-		30.50	-	23.02
218	1,085		29.50	45.00	48.00	37.50	-		35.00	3.00	28.29
219	1,090		39.50	31.00	62.00	32.33	-		38.00	1.50	29.19
220	1,095		42.00	28.00	73.00	27.00	-		38.00	-	29.71
221	1,100		45.00	36.00	73.00	25.17	-		36.50	5.50	31.60
222	1,105		50.50	48.00	76.00	28.00	-		38.00	8.50	35.57
223	1,110		54.50	36.00	81.00	25.33	-		40.50	7.00	34.90
224	1,115		54.50	14.00	73.00	18.83	-		36.50	7.00	29.12
225	1,120		51.50	8.00	78.00	19.17	-		39.00	1.50	28.17
226	1,125		47.50	25.00	84.00	26.00	-		42.00	1.50	32.29
227	1,130		47.50	22.00	87.00	35.00	-		43.50	10.00	35.00
228	1,135		51.50	14.00	92.00	39.00	-		46.00	11.50	36.29
229	1,140		52.00	14.00	90.00	41.67	-		45.00	10.00	36.10
230	1,145		56.00	3.00	90.00	42.33	-		45.00	12.50	35.55
231	1,150		57.50	3.00	90.00	44.83	-		45.00	7.00	35.33
232	1,155		49.00	-	87.00	46.33	-		43.50	8.50	33.48
233	1,160		48.00	-	90.00	53.67	-		45.00	3.00	34.24
234	1,165		49.00	-	87.00	57.67	-		43.50	4.00	34.45
235	1,170		50.50	-	90.00	56.17	-		45.00	7.00	35.52
236	1,175		57.50	-	95.00	59.20	-		47.50	8.50	38.24
237	1,180		60.00	-	98.00	60.00	-		49.00	1.50	38.36
238	1,185		60.00	-	98.00	62.00	-		49.00	-	38.43

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
239	1,190		55.00	-	90.00	60.80	-		46.50	4.00	36.61
240	1,195		52.50	-	80.00	65.00	-		47.00	1.50	35.14
241	1,200		58.50	-	92.00	68.60	-		58.50	-	39.66
242	1,205		59.00	-	90.00	71.80	-		60.50	-	40.19
243	1,210		56.00	-	87.00	71.00	-		59.00	-	39.00
244	1,215		54.50	-	84.00	62.40	6.00		60.00	-	38.13
245	1,220		56.00	-	87.00	58.20	14.00		61.50	-	39.53
246	1,225		58.50	-	92.00	56.40	8.00		68.75	-	40.52
247	1,230		54.50	-	92.00	55.20	22.00		69.75	-	41.92
248	1,235		52.00	-	84.00	55.80	31.00		67.75	-	41.51
249	1,240		51.50	-	81.00	57.60	31.00		70.00	-	41.59
250	1,245		20.00	3.00		57.60	20.00		59.00	11.00	28.43
251	1,250		31.00	14.00		60.00	11.00		48.00	8.50	28.75
252	1,255		39.00	8.00		63.20			53.00	10.00	34.64
253	1,260		45.00			61.00			59.00	11.00	44.00
254	1,265		42.00			67.50			53.00	11.00	43.38
255	1,270		48.00			66.75			48.00	9.50	43.06
256	1,275		45.00			66.00			28.00	11.00	37.50
257	1,280		36.00			68.50			20.00	8.50	33.25
258	1,285		28.00			67.00			34.00	14.00	35.75
259	1,290		39.00			64.50			31.00	9.50	36.00
260	1,295		36.00			68.50			29.50	11.50	36.38
261	1,300		45.00			75.50			22.00	8.50	37.75
262	1,305		50.00			74.00			20.00	8.00	38.00

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
263	1,310		56.00			72.50			17.00	5.50	37.75
264	1,315		59.00			77.75			20.00	8.50	41.31
265	1,320		59.00			78.50			28.00	8.50	43.50
266	1,325		59.00			84.00			22.00	7.00	43.00
267	1,330		59.00			84.00			28.00	5.50	44.13
268	1,335		53.00			81.00			25.00	5.50	41.13
269	1,340		56.00			70.00			14.00	7.00	36.75
270	1,345		64.00			78.00			10.00	9.00	40.25
271	1,350		70.00			81.00			11.00	-	40.50
272	1,355		76.00			76.00			8.00	-	40.00
273	1,360		78.00			59.00			11.00	-	37.00
274	1,365		73.00			59.00			11.00	-	35.75
275	1,370		73.00			62.00			20.00	-	38.75
276	1,375		73.00			64.00			17.00	-	38.50
277	1,380		73.00			78.00			25.00	-	44.00
278	1,385		73.00			87.00			25.00	-	46.25
279	1,390		67.00			90.00			25.00	22.00	51.00
280	1,395		64.00			90.00			36.00	17.00	51.75
281	1,400		70.00			90.00			31.00	17.00	52.00
282	1,405		67.00			94.00			34.00	17.00	53.00
283	1,410		67.00			94.00			42.00	17.00	55.00
284	1,415		67.00			94.00			43.50	20.00	56.13
285	1,420		73.00			104.00			42.00	34.00	63.25
286	1,425		78.00			101.00			50.00	36.00	66.25

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
287	1,430		84.00						50.00	34.00	56.00
288	1,435		84.00						50.00	34.00	56.00
289	1,440		76.00						50.00	20.00	48.67
290	1,445		73.00						59.00		66.00
291	1,450		70.00						62.00		66.00
292	1,455		70.00						64.00		67.00
293	1,460		67.00						73.00		70.00
294	1,465		67.00						76.00		71.50
295	1,470		73.00						76.00		74.50
296	1,475								74.50		74.50
297	1,480								64.00		64.00
298	1,485								73.00		73.00
299	1,490								70.00		70.00
300	1,495								70.00		70.00
301	1,500								78.00		78.00
302	1,505								78.00		78.00
303	1,510								84.00		84.00
304	1,515								84.00		84.00
305	1,520								78.00		78.00
306	1,525								81.00		81.00
307	1,530								70.00		70.00
308	1,535								62.00		62.00
309	1,540								67.00		67.00
310	1,545								71.50		71.50

Table A.1 All Day Average Driving Cycle for 1.5, 1.6 ,1.8 (cont.)

NO.	TIME (s)	Average Speed									
		R1 Morning	R2 Morning	R3 Morning	R1 Afternoon	R2 Afternoon	R3 Afternoon	R1 Evening	R2 Evening	R3 Evening	ALL DAY
311	1,550								72.50		72.50
312	1,555								78.00		78.00
313	1,560								81.00		81.00
314	1,565								84.00		84.00
315	1,570								90.00		90.00
316	1,575								92.50		92.50
317	1,580								92.50		92.50
318	1,585								97.50		97.50

Appendix B

Pollutants measurement with driving simulation

Table B.1 Pollutants measurement with driving simulation for Lancer 1.5 without 3-way catalytic Converter

Date : 19/03/02 1'st round Time: 3.29-3.56 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	84.5	760	0.094	5.6	0.2	200	12.6	0	68.00
60	56.50	88.4	1600	0.473	10.5	0.6	222	6.1	1.364	70.00
120	52.54	91	1650	0.847	11.6	1.1	180	5.5	1.259	85.00
180	54.54	93.6	1700	0.694	13.4	0.7	147	6.2	1.254	59.00
240	53.20	95.4	1480	0.601	13.9	0.6	133	5.6	1.24	74.00
300	43.01	96.7	1560	1.08	13	1.1	131	5.5	1.235	72.00
360	34.38	98.1	1420	0.922	12.1	1	126	7.6	1.342	49.00
420	21.48	98.3	1210	0.783	12.1	0.9	125	8.5	1.42	25.00
480	35.54	97.9	1090	0.659	12.7	0.7	123	7.9	1.379	24.00
540	22.57	97.9	1210	0.569	11.9	0.6	119	9.1	1.473	16.00
600	30.57	98	1390	0.682	12.3	0.9	118	8.5	1.413	52.00
660	31.86	98.3	1350	0.841	12.8	1.1	117	6.8	1.307	38.00
720	21.18	98.7	1040	0.817	12.3	0.8	119	8.6	1.414	24.00
780	14.83	98.6	910	0.591	12.1	0.6	116	8.8	1.441	30.00
840	12.90	98.4	930	0.845	12.1	0.7	117	8.9	1.447	60.00
900	40.55	98.7	1690	1.322	13.4	1.3	118	5.8	1.206	90.00
960	41.93	99.7	1910	1.065	12.8	1.1	116	8	1.364	121.00
1020	42.17	100.8	1730	0.968	13.8	1	119	5.8	1.235	115.00
1080	23.02	100.7	1060	1.002	13	1	119	8.4	1.368	62.00
1140	36.10	100.7	1310	0.831	13.5	1	118	8.1	1.35	56.00
1200	39.66	100.8	1660	1.06	13.7	1	119	7.5	1.307	77.00
1260	44.00	101.5	1720	1.267	13.5	1.2	119	7.5	1.306	60.00
1320	43.50	101.8	1630	0.727	13.5	0.9	116	8.4	1.37	95.00
1380	44.00	102.3	1620	0.978	14.1	0.8	115	7	1.281	60.00
1440	48.67	102.9	1220	0.898	15.2	0.9	117	5.5	1.212	134.00
1500	78.00	103.9	1740	0.771	14.5	0.8	118	5.5	1.215	145.00
1560	81.00	105.3	2270	0.798	15.3	0.7	123	5.4	1.209	135.00
1585	97.50	106.6	2400	0.756	15.5	0.8	123	3.9	1.14	82.00

Table B.2 Pollutants measurement with driving simulation for Lancer 1.5 without 3-way catalytic Converter

Date : 19/03/02 2 'nd round Time: 4.02-4.29 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	84.5	760	0.094	5.6	0.2	200	12.6	0	68.00
60	56.50	88.4	1600	0.473	10.5	0.6	222	6.1	1.364	70.00
120	52.54	91	1650	0.847	11.6	1.1	180	5.5	1.259	85.00
180	54.54	93.6	1700	0.694	13.4	0.7	147	6.2	1.254	59.00
240	53.20	95.4	1480	0.601	13.9	0.6	133	5.6	1.24	74.00
300	43.01	96.7	1560	1.08	13	1.1	131	5.5	1.235	72.00
360	34.38	98.1	1420	0.922	12.1	1	126	7.6	1.342	49.00
420	21.48	98.3	1210	0.783	12.1	0.9	125	8.5	1.42	25.00
480	35.54	97.9	1090	0.659	12.7	0.7	123	7.9	1.379	24.00
540	22.57	97.9	1210	0.569	11.9	0.6	119	9.1	1.473	16.00
600	30.57	100.4	680	0.443	11.2	0.5	105	10.1	1.564	74.51
660	31.86	100.8	1700	0.754	14.9	0.7	112	5.7	1.217	71.52
720	21.18	101.7	1620	0.656	14.9	0.6	112	6	1.243	86.01
780	14.83	102	1590	0.711	14	0.8	110	5.2	1.232	57.95
840	12.90	102.8	1580	0.781	15	0.7	111	7.4	1.3	83.25
900	40.55	103.1	1390	1.326	14.1	1.2	112	6.9	1.269	83.28
960	41.93	103.4	1720	1.381	13.9	1.3	120	8.5	1.333	47.31
1020	42.17	103.6	1310	0.869	13.7	0.9	111	8.7	1.384	27.09
1080	23.02	103.2	1350	1.18	13.7	1	116	7	1.259	26.12
1140	36.10	102.8	1000	0.611	13.9	0.7	114	8	1.357	18.40
1200	39.66	101.8	1110	1.03	13.6	1.2	117	8.4	1.359	59.06
1260	44.00	101.8	1210	0.979	13.5	0.9	114	8.8	1.381	41.61
1320	43.50	101.7	1080	0.985	12.9	1	110	8.9	1.415	29.07
1380	44.00	100.5	1020	0.586	13	0.6	106	8.6	1.417	29.95
1440	48.67	100.5	1220	0.802	13	0.8	107	8.6	1.399	59.90
1500	78.00	100.5	1600	0.717	13.1	0.7	111	5.7	1.249	94.77
1560	81.00	101	1190	0.744	13.1	0.7	106	8.1	1.372	124.70
1585	97.50	101.7	1550	0.943	15.2	0.8	107	5.2	1.185	117.92

Table B.3 Average pollutants measurement with driving simulation for Lancer1.5 without 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	92.45	720	0.2685	8.4	0.2	152.5	11.35	0.782	71.25
60	56.50	94.6	1650	0.6135	12.7	0.55	167	5.9	1.2905	70.76
120	52.54	96.35	1635	0.7515	13.25	0.9	146	5.75	1.251	85.50
180	54.54	97.8	1645	0.7025	13.7	0.65	128.5	5.7	1.243	58.48
240	53.20	99.1	1530	0.691	14.45	0.7	122	6.5	1.27	78.62
300	43.01	99.9	1475	1.203	13.55	0.9	121.5	6.2	1.252	77.64
360	34.38	100.75	1570	1.1515	13	1.1	123	8.05	1.3375	48.16
420	21.48	100.95	1260	0.826	12.9	1.1	118	8.6	1.402	26.04
480	35.54	100.55	1220	0.9195	13.2	0.8	119.5	7.45	1.319	25.06
540	22.57	100.35	1105	0.59	12.9	0.8	116.5	8.55	1.415	17.20
600	30.57	99.9	1250	0.856	12.95	0.8	117.5	8.45	1.386	55.53
660	31.86	100.05	1280	0.91	13.15	1.15	115.5	7.8	1.344	39.80
720	21.18	100.2	1060	0.901	12.6	0.85	114.5	8.75	1.4145	26.54
780	14.83	99.55	965	0.5885	12.55	0.8	111	8.7	1.429	29.98
840	12.90	99.45	1075	0.8235	12.55	0.65	112	8.75	1.423	59.95
900	40.55	99.6	1645	1.0195	13.25	1.05	114.5	5.75	1.2275	92.38
960	41.93	100.35	1550	0.9045	12.95	0.9	111	8.05	1.368	122.85
1020	42.17	101.25	1640	0.9555	14.5	0.85	113	5.5	1.21	116.46
1080	23.02	101.4	1125	0.939	13.6	0.9	115	7.25	1.303	63.39
1140	36.10	101.55	1295	0.848	13.7	1	115.5	7.65	1.3205	57.00
1200	39.66	101.7	1500	0.852	13.95	0.9	114	7.3	1.3035	78.62
1260	44.00	102	1515	0.9465	13.5	0.9	114.5	7.7	1.3295	61.43
1320	43.50	102.45	1645	0.7065	13.9	0.75	112	7.65	1.3285	95.82
1380	44.00	102.9	1595	0.8525	14.5	0.7	112.5	7.15	1.287	60.93
1440	48.67	103.4	1380	0.948	14.55	0.85	117.5	5.75	1.2255	135.63
1500	78.00	104.35	1810	0.835	14.55	0.95	116	5.45	1.21	147.91
1560	81.00	105.55	2180	0.79	15.4	0.75	119.5	5.15	1.1935	140.05
1585	97.50	106.65	2380	0.842	15.85	0.75	121.5	4.2	1.1445	86.98

Table B.4 Pollutants measurement with driving simulation for Lancer1.5 with 3-way catalytic Converter

Date : 18/03/02 1'st round Time: 1.54-2.21 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	91.3	820	0.071	18	0	92	1.1	1.033	39.50
60	56.50	91	1690	0.437	18	0.3	100	0.7	1.009	41.00
120	52.54	92.8	1660	0.335	18	0.4	109	0.4	1	44.00
180	54.54	94.6	1610	0.383	18	0.2	99	0.4	1.005	33.50
240	53.20	96	1620	0.194	18	0.1	101	0.4	1.006	45.00
300	43.01	97.4	1430	0.343	18	0.5	112	0.4	1.004	44.00
360	34.38	98.4	1800	0.234	18	0.3	109	0.4	1.007	26.50
420	21.48	99.1	1420	0.183	18	0.1	106	0.4	1.006	14.00
480	35.54	99.4	1350	0.194	18	0.1	103	0.4	1.005	13.00
540	22.57	99.5	1320	0.082	18	0	102	0.4	1.01	8.00
600	30.57	99.5	1060	0.074	18	0	105	0.4	1.008	30.00
660	31.86	99.7	1340	0.068	18	0	105	0.3	1.008	20.00
720	21.18	99.5	1000	0.162	18	0.2	104	0.4	1.004	14.00
780	14.83	98.9	910	0.069	18	0	107	0.3	1.008	16.00
840	12.90	98.5	740	0.125	18	0.11	110	0.3	1.005	33.00
900	40.55	98.6	1550	0.074	18	0	115	0.3	1.007	50.00
960	41.93	99.1	1300	0.115	18	0.1	111	0.4	1.009	68.00
1020	42.17	100	1630	0.094	18	0.1	111	0.3	1.007	65.00
1080	23.02	100.4	820	0.212	18	0.2	111	0.7	1.018	30.00
1140	36.10	100.5	1470	0.394	18	0.3	114	0.3	1	31.00
1200	39.66	100.9	1340	0.095	18	0.1	117	0.3	1.006	44.00
1260	44.00	101.4	1450	0.087	18	0	111	1.5	1.057	33.00
1320	43.50	101.8	1750	0.086	18	0	111	0.3	1.006	55.00
1380	44.00	102.2	1560	0.085	18	0	111	0.5	1.013	30.00
1440	48.67	103	1560	0.092	18	0	111	0.3	1.006	78.00
1500	78.00	104	1890	0.727	18	0.6	101	0.4	0.995	80.50
1560	81.00	105.8	2080	0.208	18	0.2	103	0.3	1.003	79.00
1585	97.50	106.9	2460	0.152	18	0.1	88	0.3	1.005	44.00

Table B.5 Pollutants measurement with driving simulation for Lancer1.5 with 3-way catalytic Converter

Date : 18/03/02 1'st round Time: 2.28-2.55 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	99.1	860	0.023	18	0	115	0.3	1.01	42.21
60	56.50	99.6	1620	0.161	18	0.1	112	0.3	1.005	40.14
120	52.54	100.5	1470	0.956	18	1.1	112	0.3	0.988	54.05
180	54.54	101.3	1540	0.114	18	0.1	105	0.4	1.007	33.56
240	53.20	102	1530	0.108	18	0.1	105	0.3	1.006	45.16
300	43.01	102.6	1450	0.081	18	0	118	0.3	1.006	45.03
360	34.38	103	1350	0.215	18	0.2	118	0.9	1.023	28.72
420	21.48	102.9	1070	0.08	18	0	104	0.3	1.008	15.87
480	35.54	102.5	1180	1.328	18	1.3	115	0.3	0.989	15.74
540	22.57	102.3	1100	0.1	18	0.1	114	0.4	1.007	11.72
600	30.57	102	1040	0.489	18	0.7	115	0.3	0.992	33.68
660	31.86	102.2	1790	0.134	18	0.1	108	0.3	1.005	25.64
720	21.18	102.1	930	0.101	18	0.1	106	0.3	1.006	16.43
780	14.83	101.7	1030	0.079	18	0	109	0.3	1.006	18.37
840	12.90	101.1	920	0.093	18	0	113	0.3	1.006	35.75
900	40.55	101	1610	0.099	18	0.1	104	0.3	1.005	55.94
960	41.93	101.3	1300	0.088	18	0	103	0.3	1.006	72.88
1020	42.17	101.9	1590	0.084	18	0	107	0.3	1.006	68.55
1080	23.02	102.4	1820	0.6	18	0.2	104	0.4	0.997	42.69
1140	36.10	102.5	1400	0.174	18	0.1	105	0.3	1.003	34.37
1200	39.66	102.7	1530	0.081	18	0	104	0.3	1.006	46.16
1260	44.00	102.9	1450	0.079	18	0	104	1	1.035	37.44
1320	43.50	103.2	1670	0.086	18	0	108	0.3	1.005	54.88
1380	44.00	103.4	1430	0.163	18	0.1	113	0.4	1.007	39.87
1440	48.67	104.1	1620	0.169	18	0.1	105	0.3	1.003	77.53
1500	78.00	105	1830	0.746	18	0.3	101	0.3	0.996	89.11
1560	81.00	106.1	2300	0.132	18	0.1	102	0.3	1.006	81.60
1585	97.50	107.2	2400	0.23	18	0.2	95	0.3	1.001	55.74

Table B.6 Average pollutants measurement with driving simulation for Lancer1.5 with 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	95.2	840	0.047	18	0	103.5	0.7	1.0215	40.85
60	56.50	95.3	1655	0.299	18	0.2	106	0.5	1.007	40.57
120	52.54	96.65	1565	0.6455	18	0.75	110.5	0.35	0.994	49.02
180	54.54	97.95	1575	0.2485	18	0.15	102	0.4	1.006	33.53
240	53.20	99	1575	0.151	18	0.1	103	0.35	1.006	45.08
300	43.01	100	1440	0.212	18	0.25	115	0.35	1.005	44.52
360	34.38	100.7	1575	0.2245	18	0.25	113.5	0.65	1.015	27.61
420	21.48	101	1245	0.1315	18	0.05	105	0.35	1.007	14.93
480	35.54	100.95	1265	0.761	18	0.7	109	0.35	0.997	14.37
540	22.57	100.9	1210	0.091	18	0.05	108	0.4	1.0085	9.86
600	30.57	100.75	1050	0.2815	18	0.35	110	0.35	1	31.84
660	31.86	100.95	1565	0.101	18	0.05	106.5	0.3	1.0065	22.82
720	21.18	100.8	965	0.1315	18	0.15	105	0.35	1.005	15.21
780	14.83	100.3	970	0.074	18	0	108	0.3	1.007	17.19
840	12.90	99.8	830	0.109	18	0.055	111.5	0.3	1.0055	34.37
900	40.55	99.8	1580	0.0865	18	0.05	109.5	0.3	1.006	52.97
960	41.93	100.2	1300	0.1015	18	0.05	107	0.35	1.0075	70.44
1020	42.17	100.95	1610	0.089	18	0.05	109	0.3	1.0065	66.77
1080	23.02	101.4	1320	0.406	18	0.2	107.5	0.55	1.0075	36.35
1140	36.10	101.5	1435	0.284	18	0.2	109.5	0.3	1.0015	32.68
1200	39.66	101.8	1435	0.088	18	0.05	110.5	0.3	1.006	45.08
1260	44.00	102.15	1450	0.083	18	0	107.5	1.25	1.046	35.22
1320	43.50	102.5	1710	0.086	18	0	109.5	0.3	1.0055	54.94
1380	44.00	102.8	1495	0.124	18	0.05	112	0.45	1.01	34.94
1440	48.67	103.55	1590	0.1305	18	0.05	108	0.3	1.0045	77.76
1500	78.00	104.5	1860	0.7365	18	0.45	101	0.35	0.9955	84.81
1560	81.00	105.95	2190	0.17	18	0.15	102.5	0.3	1.0045	80.30
1585	97.50	107.05	2430	0.191	18	0.15	91.5	0.3	1.003	49.87

Table B.7 Pollutants measurement with driving simulation for Lancer 1.6 without 3-way catalytic Converter

Date:15/03/02 1'st round Time: 2.50-3.17 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	77.2	860	0.641	17.5	0.6	237	1.9	1.049	56.00
60	56.50	80.3	1640	0.672	18	0.6	214	1.2	1.023	110.00
120	52.54	82	1570	0.768	18	0.7	213	1.2	1.018	88.00
180	54.54	83.6	1780	0.778	18	0.8	210	1.2	1.017	92.00
240	53.20	84.9	1630	0.754	18	0.7	207	1.2	1.021	89.00
300	43.01	85.9	3680	0.946	18	0.8	284	1.3	1.017	441.00
360	34.38	87.1	2230	1.014	18	1	234	1.4	1.02	175.00
420	21.48	87.9	1610	0.864	18	0.8	204	1.3	1.02	112.00
480	35.54	87.3	1430	0.823	18	0.8	222	1.4	1.024	103.00
540	22.57	88.3	1740	0.766	18	0.7	209	1.5	1.028	116.00
600	30.57	88	1230	0.796	18	0.7	208	1.5	1.031	93.00
660	31.86	87.9	1140	0.859	18	0.8	210	1.5	1.022	85.00
720	21.18	88.8	1310	0.868	18	0.9	219	1.4	1.024	94.00
780	14.83	88.4	950	0.812	18	0.8	201	1.5	1.03	71.00
840	12.90	88.5	960	0.805	18	0.8	211	1.4	1.025	73.00
900	40.55	88	1710	0.827	18	0.8	217	1.3	1.02	93.00
960	41.93	89.1	1580	0.845	18	0.8	227	1.5	1.028	87.00
1020	42.17	90.1	2970	0.825	18	0.8	208	1.2	1.017	345.00
1080	23.02	91.1	1470	0.792	18	0.8	202	1.3	1.02	101.00
1140	36.10	91	2920	0.844	18	0.8	192	1.3	1.023	341.00
1200	39.66	91.4	1510	0.79	18	0.8	200	1.4	1.027	85.00
1260	44.00	92.4	1760	0.802	18	0.8	193	1.3	1.021	92.00
1320	43.50	93	1820	0.816	18	0.8	197	1.2	1.022	102.00
1380	44.00	93.3	1660	0.923	18	0.9	192	1.4	1.024	89.00
1440	48.67	93.9	2380	0.962	17.7	0.9	235	1.4	1.02	95.00
1500	78.00	95	4000	0.949	18	0.9	177	1.2	1.018	670.00
1560	81.00	96.8	2130	0.829	18	0.8	190	1.2	1.018	321.00
1585	97.50	97.1	4660	0.818	18	0.8	151	1.1	1.016	756.00

Table B.8 Pollutants measurement with driving simulation for Lancer 1.6 without 3-way catalytic Converter

Date : 19/03/02 2'nd round Time: 3.29-3.56 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	80.3	1570	0.538	15.8	0.5	177	1.7	1.051	88.00
60	56.50	82.4	1640	0.72	17.2	0.7	209	1.4	1.027	111.00
120	52.54	84	1540	0.718	17.9	0.9	209	1.2	1.022	86.00
180	54.54	85.6	1590	0.999	18	1	210	1.3	1.015	89.00
240	53.20	87	1480	0.712	18	0.8	219	1.2	1.014	108.00
300	43.01	88	1460	1.224	18	1.1	255	1.5	1.017	104.00
360	34.38	88.7	1370	1.389	17.6	1.6	250	2	1.029	96.00
420	21.48	89.5	1750	0.782	18	0.7	219	1.3	1.02	119.00
480	35.54	89.4	1320	0.925	18	0.8	216	1.5	1.023	95.00
540	22.57	89.6	1420	1.042	18	1	214	1.6	1.026	101.00
600	30.57	89.9	1350	0.837	18	0.8	225	1.4	1.024	98.00
660	31.86	89.5	1240	0.84	18	0.8	214	1.3	1.021	94.00
720	21.18	90.2	1880	1.17	18	1.3	219	1.3	1.01	121.00
780	14.83	90.2	950	0.855	18	0.9	214	1.6	1.032	71.00
840	12.90	89.9	940	1.566	18	1.5	221	1.5	1.01	70.00
900	40.55	89	1640	1.116	18	1.1	215	1.2	1.016	111.00
960	41.93	90.1	2010	1.326	18	1.4	223	1.4	1.017	121.00
1020	42.17	91.3	3320	0.841	18	0.7	210	1.2	1.02	202.00
1080	23.02	92	2310	0.88	18	0.8	257	1.4	1.02	93.00
1140	36.10	92.2	1980	0.898	18	0.8	215	1.3	1.016	90.00
1200	39.66	92.6	1430	0.873	18	0.8	205	1.3	1.021	88.00
1260	44.00	93.1	1420	1.003	18	0.9	276	2.1	1.048	87.00
1320	43.50	93.8	1540	0.881	18	0.8	222	1.3	1.019	95.00
1380	44.00	94	2660	1.257	18	1.1	234	1.4	1.016	116.00
1440	48.67	94.7	1680	1.076	18	1	210	1.1	1.009	107.00
1500	78.00	95.1	3560	0.993	18	1.2	233	1.2	1.01	411.00
1560	81.00	97.4	4660	0.902	18	0.9	178	1.1	1.011	754.00
1585	97.50	99.7	2570	1.009	18	1	188	1	1.01	293.00

Table B.9 Average Pollutants measurement with driving simulation for Lancer1.6 without 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	78.75	1215	0.5895	16.65	0.55	207	1.8	1.05	72.00
60	56.50	81.35	1640	0.696	17.6	0.65	211.5	1.3	1.025	110.50
120	52.54	83	1555	0.743	17.95	0.8	211	1.2	1.02	87.00
180	54.54	84.6	1685	0.8885	18	0.9	210	1.25	1.016	90.50
240	53.20	85.95	1555	0.733	18	0.75	213	1.2	1.0175	98.50
300	43.01	86.95	2570	1.085	18	0.95	269.5	1.4	1.017	272.50
360	34.38	87.9	1800	1.2015	17.8	1.3	242	1.7	1.0245	135.50
420	21.48	88.7	1680	0.823	18	0.75	211.5	1.3	1.02	115.50
480	35.54	88.35	1375	0.874	18	0.8	219	1.45	1.0235	99.00
540	22.57	88.95	1580	0.904	18	0.85	211.5	1.55	1.027	108.50
600	30.57	88.95	1290	0.8165	18	0.75	216.5	1.45	1.0275	95.50
660	31.86	88.7	1190	0.8495	18	0.8	212	1.4	1.0215	89.50
720	21.18	89.5	1595	1.019	18	1.1	219	1.35	1.017	107.50
780	14.83	89.3	950	0.8335	18	0.85	207.5	1.55	1.031	71.00
840	12.90	89.2	950	1.1855	18	1.15	216	1.45	1.0175	71.50
900	40.55	88.5	1675	0.9715	18	0.95	216	1.25	1.018	102.00
960	41.93	89.6	1795	1.0855	18	1.1	225	1.45	1.0225	104.00
1020	42.17	90.7	3145	0.833	18	0.75	209	1.2	1.0185	273.50
1080	23.02	91.55	1890	0.836	18	0.8	229.5	1.35	1.02	97.00
1140	36.10	91.6	2450	0.871	18	0.8	203.5	1.3	1.0195	215.50
1200	39.66	92	1470	0.8315	18	0.8	202.5	1.35	1.024	86.50
1260	44.00	92.75	1590	0.9025	18	0.85	234.5	1.7	1.0345	89.50
1320	43.50	93.4	1680	0.8485	18	0.8	209.5	1.25	1.0205	98.50
1380	44.00	93.65	2160	1.09	18	1	213	1.4	1.02	102.50
1440	48.67	94.3	2030	1.019	17.85	0.95	222.5	1.25	1.0145	101.00
1500	78.00	95.05	3780	0.971	18	1.05	205	1.2	1.014	540.50
1560	81.00	97.1	3395	0.8655	18	0.85	184	1.15	1.0145	537.50
1585	97.50	98.4	3615	0.9135	18	0.9	169.5	1.05	1.013	524.50

Table B.10 Pollutants measurement with driving simulation for Lancer 1.6 with 3-way catalytic Converter

Date : 05/03/02 1'st round Time: 1.30-1.57 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	92.4	1720	0.014	16.2	0	40	0.9	1.038	73.00
60	56.50	89	1880	0.045	17.7	0	80	0.3	1.009	75.00
120	52.54	90.5	2860	0.038	18	0	56	0.3	1.009	89.00
180	54.54	92.6	1640	0.052	18	0	65	0.4	1.011	59.00
240	53.20	93.6	2340	0.048	18	0	66	0.2	1.007	75.00
300	43.01	93.3	3320	0.049	18	0	63	0.3	1.007	98.00
360	34.38	94.1	1300	0.051	18	0	61	0.5	1.015	22.00
420	21.48	93.6	1340	0.044	18	0	60	0.3	1.009	25.00
480	35.54	94.2	1230	0.05	18	0	67	0.3	1.01	19.00
540	22.57	94.1	800	0.051	18	0	68	0.5	1.015	16.00
600	30.57	93.8	1670	0.058	18	0	73	0.5	1.017	60.00
660	31.86	94.7	980	0.071	18	0	73	0.3	1.008	26.00
720	21.18	94.4	1070	0.065	18	0	73	0.4	1.011	30.00
780	14.83	93.8	1660	0.061	18	0	73	0.5	1.015	35.00
840	12.90	92.9	1620	0.114	18	0.1	90	0.3	1.007	48.00
900	40.55	94.3	2630	0.081	18	0	74	0.3	1.006	78.00
960	41.93	94.2	3580	0.087	18	0	76	0.3	1.008	120.00
1020	42.17	94.6	3280	0.087	18	0	75	0.3	1.009	115.00
1080	23.02	94.9	1130	0.234	18	0.2	82	0.2	1.001	42.00
1140	36.10	95.1	1240	0.173	18	0.1	85	0.3	1.004	51.00
1200	39.66	95.1	2540	0.09	18	0	80	0.2	1.004	87.00
1260	44.00	95.2	1480	0.084	18	0	79	0.3	1.006	58.00
1320	43.50	95.5	2290	0.128	18	0.1	79	0.3	1.006	74.00
1380	44.00	96.4	1870	0.071	18	0	777	0.3	1.008	65.00
1440	48.67	95.7	3240	0.062	18	0	68	0.2	1.006	105.00
1500	78.00	98.9	3700	0.053	17.8	0	66	2.2	1.083	119.00
1560	81.00	100.8	2300	0.05	11.4	0	70	11.8	1.842	90.00
1585	97.50	102	2200	0.055	17.9	0	70	3.9	1.029	88.00

Table B.11 Pollutants measurement with driving simulation for Lancer 1.6 with 3-way catalytic Converter

Date : 05/03/02 2'st round Time: 2.08-2.35 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	91.1	1730	0.096	18	0.1	93	0.5	1.013	72.00
60	56.50	91.2	1670	0.115	18	0.1	96	0.2	1.003	69.00
120	52.54	93.5	2470	0.112	18	0.1	93	0.4	1.008	85.00
180	54.54	94.3	1670	0.11	18	0.1	89	0.2	1.004	60.00
240	53.20	95.5	3060	0.135	18	0.1	92	0.2	1.003	85.00
300	43.01	94	1670	0.185	18	0.1	92	1.3	1.039	60.00
360	34.38	95	2350	0.682	18	0.6	89	1.5	1.037	76.00
420	21.48	95.5	1030	0.093	18	0	89	0.4	1.009	28.00
480	35.54	95	1370	0.189	18	0.2	97	0.3	1.002	32.00
540	22.57	95.6	960	0.11	18	0.1	92	0.5	1.015	19.00
600	30.57	94.9	1260	0.79	18	1.4	101	0.3	0.999	53.00
660	31.86	95.2	1420	0.581	18	0.5	170	0.2	0.985	55.00
720	21.18	95.8	920	0.196	18	0.2	94	0.3	1.005	24.00
780	14.83	94.6	980	0.183	18	0.1	94	0.4	1.006	26.00
840	12.90	94.2	1730	0.14	18	0.1	84	0.3	1.008	74.00
900	40.55	93.5	3160	2.116	18	2.6	127	1.8	0.987	110.00
960	41.93	94.6	3700	2.493	18	2.4	117	0.6	0.966	130.00
1020	42.17	94.7	3400	0.273	18	0.2	114	0.3	1.001	122.00
1080	23.02	95.1	1780	1.542	18	1.9	88	0.2	0.969	87.00
1140	36.10	94.6	1360	0.391	18	0.5	118	0.2	0.996	65.00
1200	39.66	95.5	2110	1.039	18	1	84	0.7	1	73.00
1260	44.00	96	1780	0.192	18	0.1	79	0.5	1.019	67.00
1320	43.50	95.9	3420	0.219	18	0.2	779	0.2	1.001	121.00
1380	44.00	96.5	1590	0.217	18	0.22	84	0.3	1.004	59.00
1440	48.67	95.7	4090	0.515	18	0.5	97	0.2	0.994	171.00
1500	78.00	97.2	4140	0.194	18	0.1	88	0.3	1.005	182.00
1560	81.00	98.3	4380	0.19	18	0.1	89	0.2	1.001	195.00
1585	97.50	99	2560	0.182	11.8	0.2	90	9	1.574	89.00

Table B.12 Average pollutants measurement with driving simulation for Lancer1.6 with 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	91.75	1725	0.055	17.1	0.05	66.5	0.7	1.0255	72.50
60	56.50	90.1	1775	0.08	17.85	0.05	88	0.25	1.006	72.00
120	52.54	92	2665	0.075	18	0.05	74.5	0.35	1.0085	87.00
180	54.54	93.45	1655	0.081	18	0.05	77	0.3	1.0075	59.50
240	53.20	94.55	2700	0.0915	18	0.05	79	0.2	1.005	80.00
300	43.01	93.65	2495	0.117	18	0.05	77.5	0.8	1.023	79.00
360	34.38	94.55	1825	0.3665	18	0.3	75	1	1.026	49.00
420	21.48	94.55	1185	0.0685	18	0	74.5	0.35	1.009	26.50
480	35.54	94.6	1300	0.1195	18	0.1	82	0.3	1.006	25.50
540	22.57	94.85	880	0.0805	18	0.05	80	0.5	1.015	17.50
600	30.57	94.35	1465	0.424	18	0.7	87	0.4	1.008	56.50
660	31.86	94.95	1200	0.326	18	0.25	121.5	0.25	0.9965	40.50
720	21.18	95.1	995	0.1305	18	0.1	83.5	0.35	1.008	27.00
780	14.83	94.2	1320	0.122	18	0.05	83.5	0.45	1.0105	30.50
840	12.90	93.55	1675	0.127	18	0.1	87	0.3	1.0075	61.00
900	40.55	93.9	2895	1.0985	18	1.3	100.5	1.05	0.9965	94.00
960	41.93	94.4	3640	1.29	18	1.2	96.5	0.45	0.987	125.00
1020	42.17	94.65	3340	0.18	18	0.1	94.5	0.3	1.005	118.50
1080	23.02	95	1455	0.888	18	1.05	85	0.2	0.985	64.50
1140	36.10	94.85	1300	0.282	18	0.3	101.5	0.25	1	58.00
1200	39.66	95.3	2325	0.5645	18	0.5	82	0.45	1.002	80.00
1260	44.00	95.6	1630	0.138	18	0.05	79	0.4	1.0125	62.50
1320	43.50	95.7	2855	0.1735	18	0.15	429	0.25	1.0035	97.50
1380	44.00	96.45	1730	0.144	18	0.11	430.5	0.3	1.006	62.00
1440	48.67	95.7	3665	0.2885	18	0.25	82.5	0.2	1	138.00
1500	78.00	98.05	3920	0.1235	17.9	0.05	77	1.25	1.044	150.50
1560	81.00	99.55	3340	0.12	14.7	0.05	79.5	6	1.4215	142.50
1585	97.50	100.5	2380	0.1185	14.85	0.1	80	6.45	1.3015	88.50

Table B.13 Pollutants measurement with driving simulation for Lancer 1.8 without 3-way catalytic Converter

Date : 19/03/02 1'st round Time: 11.06-11.33 a.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	81.4	1820	0.454	14.5	0.4	139	6.3	1.27	30.96
60	56.50	83.6	1590	0.627	17.3	0.6	160	2.7	1.082	48.69
120	52.54	85.7	3130	0.592	17.4	0.6	155	2.9	1.089	40.49
180	54.54	88.1	3340	0.623	18	0.6	150	2.8	1.085	41.65
240	53.20	90	3120	0.616	18	0.6	148	3.2	1.095	44.87
300	43.01	91.6	1440	0.728	18	0.7	161	3.6	1.109	120.85
360	34.38	92.9	2650	0.693	18	0.6	149	4	1.125	60.25
420	21.48	93.3	1790	0.552	18	0.5	140	5.3	1.178	54.20
480	35.54	93.9	1420	0.702	18	0.7	155	3.4	1.102	42.32
540	22.57	94.3	2700	0.563	17.2	0.5	129	4.7	1.165	49.89
600	30.57	94.5	1240	0.459	15.7	0.4	121	5.3	1.207	45.16
660	31.86	95.4	3660	0.58	16.2	0.5	123	4.1	1.155	41.75
720	21.18	95.6	2010	0.414	15	0.4	102	5.3	1.218	46.99
780	14.83	95.5	1860	0.458	15	0.4	105	5.1	1.209	33.06
840	12.90	95.3	1930	0.388	14.3	0.4	96	5.9	1.259	31.51
900	40.55	95.8	2950	0.501	16.9	0.5	126	3	1.101	43.02
960	41.93	96.2	3360	0.62	16.5	0.6	123	4.8	1.172	42.83
1020	42.17	96.9	3540	0.641	17.8	0.6	119	3.7	1.117	123.75
1080	23.02	97.1	1860	0.572	17.1	0.5	121	4	1.14	39.51
1140	36.10	97.1	2700	0.622	17.2	0.6	119	3.9	1.136	96.42
1200	39.66	97.4	2690	0.61	17.3	0.6	118	3.6	1.117	36.04
1260	44.00	97.8	1200	0.668	16.1	0.6	117	4.8	1.184	37.75
1320	43.50	98	2970	0.525	17.1	0.5	106	3.4	1.116	37.87
1380	44.00	98.1	2830	0.72	16.6	0.7	101	4.1	1.139	40.48
1440	48.67	98.9	3170	0.732	17.1	0.6	108	2.4	1.069	38.12
1500	78.00	100.6	3970	0.683	17.1	0.7	95	2.4	1.069	248.64
1560	81.00	102.1	4190	0.732	18	0.7	94	2.3	1.066	247.93
1585	97.50	103.4	4780	0.695	18	0.6	71	2	1.055	231.20

Table B.14 Pollutants measurement with driving simulation for Lancer 1.8 without 3-way catalytic Converter

Date : 19/03/02 2'st round Time: 11.36-12.03 a.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	99.2	1550	0.424	15.7	0.4	80	4.9	1.193	34.00
60	56.50	99.1	2600	0.483	16.5	0.5	95	2.8	1.097	51.00
120	52.54	99.4	3160	0.572	16	0.5	89	3.1	1.115	38.00
180	54.54	99.9	2930	0.5	16	0.5	86	3.1	1.109	40.00
240	53.20	100	2900	0.513	15.8	0.5	79	3.4	1.127	44.00
300	43.01	100	2910	0.547	16	0.5	72	3.4	1.127	125.00
360	34.38	100.3	2490	0.561	15.8	0.5	89	3.9	1.147	62.00
420	21.48	99.9	1960	0.468	14.8	0.4	66	4.7	1.197	50.00
480	35.54	99.6	2670	0.6	14.8	0.5	68	5.1	1.202	47.00
540	22.57	99.2	2240	0.434	14.4	0.4	62	4.5	1.202	48.00
600	30.57	99	2440	0.576	14.5	0.5	75	4.6	1.173	41.00
660	31.86	99.2	2540	0.531	15.3	0.5	79	2.7	1.096	39.00
720	21.18	98.9	2260	0.49	14.3	0.5	51	5.5	1.24	50.00
780	14.83	98.4	2030	0.394	14.5	0.3	48	5.5	1.238	31.00
840	12.90	97.8	1910	0.408	14	0.4	47	5.5	1.25	33.00
900	40.55	98.3	3340	0.632	15	0.6	74	3.9	1.154	49.00
960	41.93	98.7	3390	0.689	16	0.6	73	4.1	1.157	51.00
1020	42.17	99.2	3210	0.53	16.5	0.5	68	3	1.107	123.00
1080	23.02	98.8	2000	0.637	16.3	0.6	69	3.1	1.116	48.00
1140	36.10	98.7	1300	0.513	15.9	0.5	72	3.9	1.144	98.00
1200	39.66	99	1600	0.55	16.2	0.5	74	3.7	1.134	42.00
1260	44.00	99.3	1670	0.753	15.6	0.8	67	5.1	1.2	43.00
1320	43.50	99.6	3200	0.492	16.6	0.4	72	3.6	1.129	51.00
1380	44.00	99.5	1780	0.51	16.7	0.5	72	3.6	1.128	52.00
1440	48.67	100.2	2490	0.653	17.4	0.6	82	3.8	1.135	53.00
1500	78.00	101.8	4120	0.696	17.6	0.6	73	3.9	1.127	239.00
1560	81.00	103.7	4100	0.695	17.7	0.7	52	2.4	1.071	237.00
1585	97.50	105	2510	0.625	17.8	0.6	29	2.2	1.068	242.00

Table B.15 Average pollutants measurement with driving simulation for Lancer1.8 without 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	90.3	1685	0.439	15.1	0.4	109.5	5.6	1.2315	32.48
60	56.50	91.35	2095	0.555	16.9	0.55	127.5	2.75	1.0895	49.85
120	52.54	92.55	3145	0.582	16.7	0.55	122	3	1.102	39.25
180	54.54	94	3135	0.5615	17	0.55	118	2.95	1.097	40.82
240	53.20	95	3010	0.5645	16.9	0.55	113.5	3.3	1.111	44.43
300	43.01	95.8	2175	0.6375	17	0.6	116.5	3.5	1.118	122.92
360	34.38	96.6	2570	0.627	16.9	0.55	119	3.95	1.136	61.12
420	21.48	96.6	1875	0.51	16.4	0.45	103	5	1.1875	52.10
480	35.54	96.75	2045	0.651	16.4	0.6	111.5	4.25	1.152	44.66
540	22.57	96.75	2470	0.4985	15.8	0.45	95.5	4.6	1.1835	48.94
600	30.57	96.75	1840	0.5175	15.1	0.45	98	4.95	1.19	43.08
660	31.86	97.3	3100	0.5555	15.75	0.5	101	3.4	1.1255	40.37
720	21.18	97.25	2135	0.452	14.65	0.45	76.5	5.4	1.229	48.49
780	14.83	96.95	1945	0.426	14.75	0.35	76.5	5.3	1.2235	32.03
840	12.90	96.55	1920	0.398	14.15	0.4	71.5	5.7	1.2545	32.25
900	40.55	97.05	3145	0.5665	15.95	0.55	100	3.45	1.1275	46.01
960	41.93	97.45	3375	0.6545	16.25	0.6	98	4.45	1.1645	46.91
1020	42.17	98.05	3375	0.5855	17.15	0.55	93.5	3.35	1.112	123.38
1080	23.02	97.95	1930	0.6045	16.7	0.55	95	3.55	1.128	43.76
1140	36.10	97.9	2000	0.5675	16.55	0.55	95.5	3.9	1.14	97.21
1200	39.66	98.2	2145	0.58	16.75	0.55	96	3.65	1.1255	39.02
1260	44.00	98.55	1435	0.7105	15.85	0.7	92	4.95	1.192	40.37
1320	43.50	98.8	3085	0.5085	16.85	0.45	89	3.5	1.1225	44.43
1380	44.00	98.8	2305	0.615	16.65	0.6	86.5	3.85	1.1335	46.24
1440	48.67	99.55	2830	0.6925	17.25	0.6	95	3.1	1.102	45.56
1500	78.00	101.2	4045	0.6895	17.35	0.65	84	3.15	1.098	243.82
1560	81.00	102.9	4145	0.7135	17.85	0.7	73	2.35	1.0685	242.47
1585	97.50	104.2	3645	0.66	17.9	0.6	50	2.1	1.0615	236.60

Table B.16 Pollutants measurement with driving simulation for Lancer1.8 with 3-way catalytic Converter

Date : 13/03/02 1'st round Time: 11.07-11.37 a.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	88.3	1610	0.029	18	0	41	0.7	1.026	22.00
60	56.50	88.4	2980	0.022	18	0	31	0.6	1.022	24.00
120	52.54	89.9	3100	0.02	18	0	26	0.6	1.022	26.00
180	54.54	91.2	3020	0.017	18	0	22	0.6	1.022	18.00
240	53.20	92.3	3010	0.014	18	0	20	0.7	1.029	25.00
300	43.01	93.3	3210	0.028	18	0	20	0.6	1.021	24.00
360	34.38	94.2	3320	0.011	18	0	22	0.9	1.036	15.00
420	21.48	94.7	1700	0.011	18	0	18	0.6	1.022	7.00
480	35.54	94.6	2520	0.009	18	0	13	0.6	1.022	8.00
540	22.57	94.6	2450	0.004	18	0	10	0.6	1.025	4.00
600	30.57	94.7	1150	0.002	18	0	8	0.7	1.028	19.00
660	31.86	94.8	2650	0	18	0	0	0.5	1.023	12.00
720	21.18	94.8	2140	0	18	0	1	0.6	1.024	8.50
780	14.83	94.5	1770	0	18	0	2	0.7	1.027	9.50
840	12.90	94.4	2050	0	18	0	1	0.6	1.023	19.50
900	40.55	94.2	3150	0.005	18	0	1	1.2	1.046	28.00
960	41.93	94.7	2670	0.001	18	0	4	0.6	1.024	39.00
1020	42.17	95.3	3160	0	18	0	2	0.5	1.022	37.00
1080	23.02	95.6	1760	0	18	0	0	0.5	1.022	20.00
1140	36.10	95.5	2610	0.006	18	0	1	0.5	1.021	17.00
1200	39.66	95.6	2650	0.004	18	0	4	0.5	1.021	25.00
1260	44.00	96.1	2500	0.001	18	0	1	1	1.039	18.00
1320	43.50	96.3	3100	0	18	0	0	0.5	1.021	30.00
1380	44.00	96.6	2920	0.001	18	0	0	0.5	1.021	18.00
1440	48.67	97	3210	0.014	18	0	0	0.5	1.02	44.00
1500	78.00	97.5	3840	0.001	18	0	2	0.6	1.025	47.00
1560	81.00	99.5	4320	0.013	18	0	1	0.5	1.021	45.00
1585	97.50	100.9	4050	0.005	18	0	3	0.5	1.02	25.00

Table B.17 Pollutants measurement with driving simulation for Lancer 1.8 with 3-way catalytic Converter

Date: 12/03/02 2'st round Time: 4.16-4.43 p.m. Duration: 1585 sec

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	77.8	1710	0.137	18	0.1	157	0.9	1.025	47.28
60	56.50	80.5	3420	0.137	18	0.1	96	0.5	1.014	46.96
120	52.54	83.3	2040	0.112	18	0.1	69	0.5	1.015	56.74
180	54.54	86.1	2750	0.24	18	0.2	67	0.5	1.012	38.81
240	53.20	88.5	1640	0.107	18	0.1	66	0.5	1.015	52.18
300	43.01	90.1	1640	0.15	18	0.1	64	0.7	1.021	51.52
360	34.38	91.5	1370	0.708	18	0.7	64	0.5	1.004	31.96
420	21.48	92	2820	0.345	18	0.4	64	0.5	1.007	17.28
480	35.54	92.7	1500	0.156	18	0.1	66	0.5	1.015	16.63
540	22.57	92.9	1270	0.125	18	0.1	63	0.5	1.015	11.41
600	30.57	93.2	1580	0.076	18	0	60	0.5	1.016	36.85
660	31.86	93.3	2710	0.084	18	0	60	0.5	1.016	26.41
720	21.18	93.4	2320	0.137	18	0.1	55	0.5	1.015	17.61
780	14.83	93.2	1930	0.042	18	0	47	0.5	1.018	19.89
840	12.90	92.5	2200	0.031	18	0	38	0.6	1.02	39.78
900	40.55	92.5	3190	0.029	18	0	38	0.5	1.019	61.31
960	41.93	93.3	3860	0.342	18	0.3	35	0.6	1.014	81.53
1020	42.17	94.1	3100	0.073	18	0	38	0.5	1.017	77.29
1080	23.02	94.4	2840	0.053	18	0	46	0.6	1.02	42.07
1140	36.10	95	1560	0.076	18	0	44	0.5	1.016	37.83
1200	39.66	95.6	3410	0.048	18	0	46	0.6	1.021	52.18
1260	44.00	96.2	2630	0.055	18	0	44	0.5	1.016	40.76
1320	43.50	96.9	3670	0.59	18	0.5	40	0.5	1.004	63.59
1380	44.00	97.6	1870	0.068	18	0.1	47	0.4	1.015	40.44
1440	48.67	98.2	3760	0.088	18	0	48	0.6	1.018	90.00
1500	78.00	101.4	5630	0.11	18	0.1	75	0.4	1.012	98.16
1560	81.00	104.5	3790	0.187	18	0.2	89	0.4	1.011	92.94
1585	97.50	103.1	1910	0.97	18	0.7	112	0.6	1.002	57.72

Table B.18 Average pollutants measurement with driving simulation for Lancer1.8 with 3-way catalytic Converter

Time (sec)	Speed (km/h)	Temp (°C)	N (rpm)	CO (%)	CO_2 (%)	CO vrai (%)	HC (ppm)	O_2 (%)	λ	NO_X (ppm)
0	0.00	83.05	1660	0.083	18	0.05	99	14.2	1.0255	23.64
60	56.50	84.45	3200	0.0795	18	0.05	63.5	14.76	1.018	23.48
120	52.54	86.6	2570	0.066	18	0.05	47.5	11.74	1.0185	28.37
180	54.54	88.65	2885	0.1285	18	0.1	44.5	9.94	1.017	19.40
240	53.20	90.4	2325	0.0605	18	0.05	43	8.76	1.022	26.09
300	43.01	91.7	2425	0.089	18	0.05	42	8.4	1.021	25.76
360	34.38	92.85	2345	0.3595	18	0.35	43	8.8	1.02	15.98
420	21.48	93.35	2260	0.178	18	0.2	41	8.4	1.0145	8.64
480	35.54	93.65	2010	0.0825	18	0.05	39.5	6.54	1.0185	8.32
540	22.57	93.75	1860	0.0645	18	0.05	36.5	4.94	1.02	5.71
600	30.57	93.95	1365	0.039	18	0	34	3.96	1.022	18.42
660	31.86	94.05	2680	0.042	18	0	30	1.94	1.0195	13.21
720	21.18	94.1	2230	0.0685	18	0.05	28	0.52	1.0195	8.80
780	14.83	93.85	1850	0.021	18	0	24.5	0.96	1.0225	9.95
840	12.90	93.45	2125	0.0155	18	0	19.5	0.98	1.0215	19.89
900	40.55	93.35	3170	0.017	18	0	19.5	0.86	1.0325	30.65
960	41.93	94	3265	0.1715	18	0.15	19.5	1.48	1.019	40.76
1020	42.17	94.7	3130	0.0365	18	0	20	1.52	1.0195	38.64
1080	23.02	95	2300	0.0265	18	0	23	0.72	1.021	21.03
1140	36.10	95.25	2085	0.041	18	0	22.5	0.5	1.0185	18.91
1200	39.66	95.6	3030	0.026	18	0	25	1.32	1.021	26.09
1260	44.00	96.15	2565	0.028	18	0	22.5	1.4	1.0275	20.38
1320	43.50	96.6	3385	0.295	18	0.25	20	0.6	1.0125	31.79
1380	44.00	97.1	2395	0.0345	18	0.05	23.5	0.28	1.018	20.22
1440	48.67	97.6	3485	0.051	18	0	24	0.32	1.019	45.00
1500	78.00	99.45	4735	0.0555	18	0.05	38.5	0.7	1.0185	49.08
1560	81.00	102	4055	0.1	18	0.1	45	0.9	1.016	46.47
1585	97.50	102	2980	0.4875	18	0.35	57.5	1.12	1.011	28.86

Appendix C

Photographs of the experiment

Figure C.1 Location of start-finish test runs

Figure C.2 Mut-II measuring driving parameters

Figure C.3 Equipment for finding driving cycle

Figure C.4 Equipment installing in test car

Figure C.5 Video Tape recorder in back seat

Figure C.6 Data List was shown in note book computer monitor

Figure C.7 Test cars was set on chassis dynamometer

Figure C.8 View of exhaust gas measuring equipment installed with test car

Figure C.9 View of test car on fixed on chassis dynamometer

Figure C.10 View of exhaust gas probe mounted on exhaust pipe

Figure C.11 Test car with front roller

Figure C.12 Video tape recorder for obtained data

Figure C.13 Prepare the driving simulation test

Figure C.14 Recording data while performing driving simulation

Figure C.15 Engine with detecting equipment

Figure C.16 Inside test car equipment

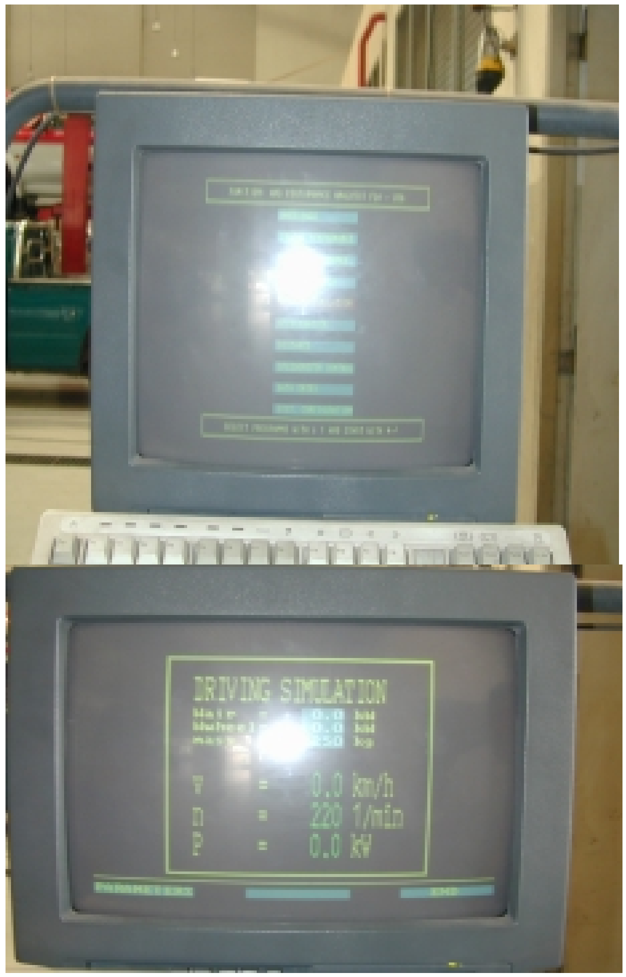

Figure C.17 Data input for each parameters

Figure C.18 View of engine performance while simulated driving

Appendix D

Number of vehicles registered in Thailand

(1996-2001)

Table D.1 Number of vehicles registered in Thailand (31 December 1996)

Type of Vehicle	Total	Bangkok	Others
Grand Total	16,093,896	3,549,082	12,544,814
Total vehicles under motor vehicle act	15,388,669	3,424,970	11,963,699
Sedan (Not more than 7 pass.)	1,567,307	1,026,233	541,074
Microbus & passenger pick up	531,295	316,580	214,715
Van & pick up	2,256,052	462,803	1,793,249
Motortricycle	3,161	911	2,250
Interprovincial taxi	337	288	49
Urban taxi	56,497	53,944	2,553
Fixed route taxi	9,134	8,483	651
Motortricycle taxi (tuk tuk)	47,281	7,406	39,875
Hotel taxi	1,003	747	256
Tour taxi	725	696	29
Car for hire	435	435	0
Motorcycle	10,713,678	1,527,834	9,185,844
Tractor	96,405	14,691	81,714
Road roller	5,849	3,148	2,701
Farm's vehicle	96,090	69	96,021
Automobile's trailer	3,420	702	2,718
Total vehicles under Land Transport act	681,411	122,881	558,530
Bus : Total	90,419	24,647	65,772
Fixed route bus	66,060	14,153	51,907
Non fixed route bus	17,177	6,372	10,805
Private Bus	7,182	4,122	3,060
Truck : Total	566,794	98,234	468,560
Non fixed route truck	65,355	29,698	35,657
Private truck	501,439	68,536	432,903
Small rural bus	24,198	0	24,198
Total vehicles under non motorized vehicle act	23,816	1,231	22,585

<u>Note</u> From Land Transport Department, 2002

Table D.2 Number of vehicles registered in Thailand (31 December 1997)

Type of Vehicle	Total	Bangkok	Others
Grand Total	17,666,240	3,872,327	13,793,913
Total vehicles under motor vehicle act	16,906,589	3,735,251	13,171,338
Sedan (Not more than 7 pass.)	1,812,415	1,156,361	656,054
Microbus & passenger pick up	537,997	319,546	218,451
Van & pick up	2,587,253	552,835	2,034,418
Motortricycle	2,535	901	1,634
Interprovincial taxi	391	287	104
Urban taxi	53,442	51,133	2,309
Fixed route taxi	9,066	8,447	619
Motortricycle taxi (tuk tuk)	47,915	7,400	40,515
Hotel taxi	1,009	783	226
Tour taxi	653	624	29
Car for hire	423	423	0
Motorcycle	11,649,959	1,616,622	10,033,337
Tractor	106,704	15,542	91,162
Road roller	7,040	3,581	3,459
Farm’s vehicle	86,446	69	86,377
Automobile’s trailer	3,341	697	2,644
Total vehicles under Land Transport act	727,997	135,845	592,152
Bus : Total	93,061	25,391	67,670
Fixed route bus	66,974	14,382	52,592
Non fixed route bus	18,772	6,971	11,801
Private Bus	7,315	4,038	3,277
Truck : Total	612,882	110,454	502,428
Non fixed route truck	71,145	31,236	39,909
Private truck	541,737	79,218	462,519
Small rural bus	22,054	0	22,054
Total vehicles under non motorized vehicle act	31,654	1,231	30,423

Note From Land Transport Department, 2002

Table D.3 Number of vehicles registered in Thailand (31 December 1998)

Type of Vehicle	Total	Bangkok	Others
Grand Total	18,860,512	4,016,594	14,843,918
Total vehicles under motor vehicle act	18,088,478	3,885,844	14,202,634
Sedan (Not more than 7 pass.)	1,974,345	1,231,899	742,446
Microbus & passenger pick up	554,851	317,013	237,838
Van & pick up	2,779,328	594,617	2,184,711
Motortricycle	2,518	901	1,617
Interprovincial taxi	366	282	84
Urban taxi	58,811	56,451	2,360
Fixed route taxi	9,072	8,345	727
Motortricycle taxi (tuk tuk)	47,211	7,406	39,805
Hotel taxi	941	609	332
Tour taxi	616	582	34
Car for hire	414	414	0
Motorcycle	12,464,499	1,646,738	10,817,761
Tractor	108,565	15,961	92,604
Road roller	8,011	3,843	4,168
Farm's vehicle	75,470	64	75,406
Automobile's trailer	3,460	719	2,741
Total vehicles under Land Transport act	741,358	129,519	611,839
Bus : Total	96,641	24,975	71,666
Fixed route bus	69,711	14,147	55,564
Non fixed route bus	19,785	7,019	12,766
Private Bus	7,145	3,809	3,336
Truck : Total	621,474	104,544	516,930
Non fixed route truck	72,186	31,348	40,838
Private truck	549,288	73,196	476,092
Small rural bus	23,243	0	23,243
Total vehicles under non motorized vehicle act	30,676	1,231	29,445

Note From Land Transport Department, 2002

Table D.4 Number of vehicles registered in Thailand (31 December 1999)

Type of Vehicle	Total	Bangkok	Others
Grand Total	20,096,536	4,162,846	15,933,690
Total vehicles under motor vehicle act	19,333,726	4,037,615	15,296,111
Sedan (Not more than 7 pass.)	2,123,590	1,317,062	806,528
Microbus & passenger pick up	526,871	289,116	237,755
Van & pick up	3,097,831	664,080	2,433,751
Motortricycle	2,535	885	1,650
Interprovincial taxi	334	249	85
Urban taxi	64,072	61,950	2,122
Fixed route taxi	8,796	8,229	567
Motortricycle taxi (tuk tuk)	50,455	7,405	43,050
Hotel taxi	1,117	960	157
Tour taxi	354	317	37
Car for hire	127	106	21
Motorcycle	13,244,961	1,660,119	11,584,842
Tractor	110,971	20,167	90,804
Road roller	10,712	5,769	4,943
Farm’s vehicle	87,442	64	87,378
Automobile’s trailer	3,558	1,137	2,421
Total vehicles under Land Transport act	731,210	124,000	607,210
Bus : Total	95,801	24,928	70,873
Fixed route bus	69,610	13,785	55,825
Non fixed route bus	18,911	7,361	11,550
Private Bus	7,280	3,782	3,498
Truck : Total	613,343	99,072	514,271
Non fixed route truck	72,609	31,819	40,790
Private truck	540,734	67,253	473,481
Small rural bus	22,066	0	22,066
Total vehicles under non motorized vehicle act	31,600	1,321	30,369

Note From Land Transport Department, 2002

Table D.5 Number of vehicles registered in Thailand (31 December 2000)

Type of Vehicle	Total	Bangkok	Others
Grand Total	20,835,684	4,496,618	16,339,066
Total vehicles under motor vehicle act	20,030,220	4,349,096	15,681,124
Sedan (Not more than 7 pass.)	2,111,163	1,240,985	870,178
Microbus & passenger pick up	554,242	295,527	258,715
Van & pick up	3,209,525	737,476	2,472,049
Motortricycle	4,679	1,276	3,403
Interprovincial taxi	321	274	74
Urban taxi	66,449	64,321	2,128
Fixed route taxi	8,779	8,187	592
Motortricycle taxi (tuk tuk)	47,227	7,403	39,824
Hotel taxi	1,268	859	409
Tour taxi	375	321	54
Car for hire	179	96	83
Motorcycle	13,816,560	1,964,850	11,851,710
Tractor	111,302	20,518	90,784
Road roller	11,689	5,828	5,861
Farm’s vehicle	83,157	64	83,093
Automobile’s trailer	3,305	1,138	2,167
Total vehicles under Land Transport act	774,707	146,291	628,416
Bus : Total	100,920	26,128	74,792
Fixed route bus	73,255	15,379	57,876
Non fixed route bus	18,746	6,961	11,785
Private Bus	8,919	3,788	5,131
Truck : Total	652,520	120,163	532,357
Non fixed route truck	83,453	40,442	43,011
Private truck	569,067	79,721	489,346
Small rural bus	21,267	0	21,267
Total vehicles under non motorized vehicle act	30,757	1,321	29,526

Note From Land Transport Department, 2002

Table D.6 Number of vehicles registered in Thailand (31 December 2001)

Type of Vehicle	Total	Bangkok	Others
Grand Total	22,589,185	4,464,158	18,125,027
Total vehicles under motor vehicle act	21,760,467	4,307,281	17,453,186
Sedan (Not more than 7 pass.)	2,280,676	1,322,643	958,033
Microbus & passenger pick up	583,299	356,685	226,614
Van & pick up	3,341,448	671,470	2,669,978
Motortricycle	2,147	530	1,617
Interprovincial taxi	388	326	62
Urban taxi	69,037	67,019	2,018
Fixed route taxi	9,128	8,416	712
Motortricycle taxi (tuk tuk)	46,821	7,406	39,415
Hotel taxi	2,221	1,705	516
Tour taxi	498	395	103
Car for hire	538	209	329
Motorcycle	15,236,081	1,853,788	13,382,293
Tractor	99,449	13,123	86,326
Road roller	8,612	2,857	5,755
Farm's vehicle	77,899	3	77,896
Automobile's trailer	2,225	706	1,519
Total vehicles under Land Transport act	803,869	156,763	647,106
Bus : Total	107,622	30,745	76,877
Fixed route bus	77,944	18,543	59,401
Non fixed route bus	20,885	8,067	12,818
Private Bus	8,793	4,135	4,658
Truck : Total	673,599	126,018	547,581
Non fixed route truck	90,181	42,862	47,319
Private truck	583,418	83,156	500,262
Small rural bus	22,648	-	22,648
Total vehicles under non motorized vehicle act	24,849	114	24,735

Note From Land Transport Department, 2002

Appendix E

Statistical Analysis

Table E.1 Results of exhaust emissions for test car Lancer 1.5 with and without 3-way catalytic converter

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
Without 3-way catalytic converter	152.5	0.2685	71.25	8.4
	167	0.6135	70.76	12.7
	146	0.7515	85.5	13.25
	128.5	0.7025	58.48	13.70
	122	0.691	78.62	14.45
	121.5	1.203	77.64	13.55
	123	1.1515	48.16	13.00
	118	0.826	26.04	12.90
	119.5	0.9195	25.06	13.20
	116.5	0.59	17.20	12.90
	117.5	0.856	55.53	12.95
	115.5	0.91	39.80	13.15
	114.5	0.901	26.54	12.60
	111	0.5885	29.98	12.55
	112	0.8235	59.95	12.55
	114.5	1.0195	92.38	13.25
	111	0.9045	122.85	12.95
	113	0.9555	116.46	14.5
	115	0.939	63.39	13.60
	115.5	0.848	57.00	13.70
	114	0.852	78.62	13.95
	114.5	0.9465	61.43	13.50
	112	0.7065	95.82	13.90
	112.5	0.8525	60.93	14.50
	117.5	0.948	135.63	14.55
	116	0.835	147.91	14.55
	119.5	0.76	140.05	15.40
	121.5	0.842	86.98	15.85
average	120.77	0.83	72.50	13.43
With 3-way catalytic converter	103.5	0.047	40.85	18
	106	0.299	40.57	18
	110.5	0.6455	49.02	18
	102	0.2485	33.53	18
	103	0.151	45.08	18
	115	0.212	44.52	18
	113.5	0.2245	27.61	18
	105	0.1315	14.93	18
	109	0.761	14.37	18
	108	0.091	9.86	18
	110	0.2815	31.84	18

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
With 3-way catalytic converter	106.5	0.101	22.82	18
	105	0.1315	15.21	18
	108	0.074	17.19	18
	111.5	0.109	34.37	18
	109.5	0.0865	52.97	18
	107	0.1015	70.44	18
	109	0.089	66.77	18
	107.5	0.406	36.35	18
	109.5	0.284	32.68	18
	110.5	0.088	45.08	18
	107.5	0.083	35.22	18
	109.5	0.086	54.94	18
	112	0.124	34.94	18
	108	0.1305	77.76	18
	101	0.7365	84.81	18
	102.5	0.17	80.30	18
	91.5	0.191	49.87	18
Average	107.20	0.2173	41.5678	18

Table E.2 Statistical Analysis by t-test for Lancer 1.5

HC	CO	NO_X	CO_2
13.57±5.2696	0.61254±0.10108	30.931±15.5927	-4.57±0.4932

Table E.3 Results of exhaust emissions for test car Lancer 1.6 with and without 3-way catalytic converter

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
Without 3-way catalytic converter	207	0.5895	72.00	16.65
	211.5	0.696	110.50	17.60
	211	0.743	87.00	17.95
	210	0.8885	90.50	18.00
	213	0.733	98.50	18.00
	269.5	1.085	272.50	18.00
	242	1.2015	135.50	17.80
	211.5	0.823	115.50	18.00
	219	0.874	99.00	18.00
	211.5	0.904	108.50	18.00
	216.5	0.8165	95.50	18.00
	212	0.8495	89.50	18.00
	219	1.019	107.50	18.00
	207.5	0.8335	71.00	18.00
	216	1.1855	71.50	18.00
	216	0.9715	102.00	18.00
	225	1.0855	104.00	18.00
	209	0.833	273.50	18.00
	229.5	0.836	97.00	18.00
	203.5	0.871	215.50	18.00
	202.5	0.8315	86.50	18.00
	234.5	0.9025	89.50	18.00
	209.5	0.8485	98.50	18.00
	213	1.09	102.50	18.00
	222.5	1.019	101.00	17.85
	205	0.971	540.50	18.00
	184	0.8655	537.50	18.00
	169.5	0.9135	524.50	18.00
average	214.3035	0.9028	160.6071	17.9232
With 3-way catalytic converter	66.5	0.055	72.50	17.10
	88	0.08	72.00	17.85
	74.5	0.075	87.00	18.00
	77	0.081	59.50	18.00
	79	0.0915	80.00	18.00
	77.5	0.117	79.00	18.00
	75	0.3665	49.00	18.00
	74.5	0.0685	26.50	18.00
	82	0.1195	25.50	18.00
	80	0.0805	17.50	18.00
	87	0.424	56.50	18.00

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
With 3-way catalytic converter	121.5	0.326	40.50	18.00
	83.5	0.1305	27.00	18.00
	83.5	0.122	30.50	18.00
	87	0.127	61.00	18.00
	100.5	1.0985	94.00	18.00
	96.5	1.29	125.00	18.00
	94.5	0.18	118.50	18.00
	85	0.888	64.50	18.00
	101.5	0.282	58.00	18.00
	82	0.5645	80.00	18.00
	79	0.138	62.50	18.00
	429	0.1735	97.50	18.00
	430.5	0.144	62.00	18.00
	82.5	0.2885	138.00	18.00
	77	0.1235	150.50	17.90
	79.5	0.12	142.50	14.70
	80	0.1185	88.50	14.85
Average	109.0714	0.2740	73.7678	17.7285

Table E.4 Statistical Analysis by t-test for Lancer 1.6

HC	CO	NO_X	CO_2
105.23±35.2096	0.62882±0.13173	86.833±55.7386	0.1947±0.3379

Table E.5 Results of exhaust emissions for test car Lancer 1.8 with and without 3-way catalytic converter

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
Without 3-way catalytic converter	109.50	0.439	32.48	15.10
	127.50	0.555	49.85	16.90
	122.00	0.582	39.25	16.70
	118.00	0.5615	40.82	17.00
	113.50	0.5645	44.43	16.90
	116.50	0.6375	122.92	17.00
	119.00	0.627	61.12	16.90
	103.00	0.510	52.10	16.40
	111.50	0.651	44.66	16.40
	95.50	0.4985	48.94	15.80
	98.00	0.5175	43.08	15.10
	101.00	0.5555	40.37	15.75
	76.50	0.452	48.49	14.65
	76.50	0.426	32.03	14.75
	71.50	0.398	32.25	14.15
	100.00	0.5665	46.01	15.95
	98.00	0.6545	46.91	16.25
	93.50	0.5855	123.38	17.15
	95.00	0.6045	43.76	16.70
	95.50	0.5675	97.21	16.55
	96.00	0.580	39.02	16.75
	92.00	0.7105	40.37	15.85
	89.00	0.5085	44.43	16.85
	86.50	0.6150	46.24	16.65
	95.00	0.6925	45.56	17.25
	84.00	0.6895	243.82	17.35
	73.00	0.7135	242.47	17.85
	50.00	0.660	236.60	17.90
average	96.6785	0.5758	72.4489	16.3767
With 3-way catalytic converter	99.00	0.0830	23.64	18.00
	63.50	0.0795	23.48	18.00
	47.50	0.0660	28.37	18.00
	44.50	0.1285	19.40	18.00
	43.00	0.0605	26.09	18.00
	42.00	0.0890	25.76	18.00
	43.00	0.3595	15.98	18.00
	41.00	0.1780	8.64	18.00
	39.50	0.0825	8.32	18.00
	36.50	0.0645	5.71	18.00
	34.00	0.0390	18.42	18.00

Pollution Control Equipment	Emissions			
	HC(ppm	CO(%)	NO_X(ppm)	CO_2(%)
With 3-way catalytic converter	30.00	0.0420	13.21	18.00
	28.00	0.0685	8.80	18.00
	24.50	0.0210	9.95	18.00
	19.50	0.0155	19.89	18.00
	19.50	0.0170	30.65	18.00
	19.50	0.1715	40.76	18.00
	20.00	0.0365	38.64	18.00
	23.00	0.0265	21.03	18.00
	22.50	0.0410	18.91	18.00
	25.00	0.0260	26.09	18.00
	22.50	0.0280	20.38	18.00
	20.00	0.2950	31.79	18.00
	23.50	0.0345	20.22	18.00
	24.00	0.0510	45.00	18.00
	38.50	0.0555	49.08	18.00
	45.00	0.1000	46.47	18.00
	57.50	0.4875	28.86	18.00
Average	35.5714	0.09810	24.055	18.00

Table E.6 Statistical Analysis by t-test for Lancer 1.8

HC	CO	NO_X	CO_2
61.1071±9.3386	0.4777±0.05318	48.3939±24.5957	-1.6233±0.3582

From the analysis by t-test can be summarized as following :

1. There are significant difference in HC, CO, NO_X ,and CO_2 change between two groups of test car with and without 3-way catalytic converter for Lancer1.5
2. There are significant difference in HC, CO, NO_X ,and CO_2 change between two groups of test car with and without 3-way catalytic converter for Lancer1.6
3. There are significant difference in HC, CO, NO_X ,and CO_2 change between two groups of test car with and without 3-way catalytic converter for Lancer1.8

Biography

Mr.Krissadang Sookramoon was born on April 26, 1974. He graduated with his bachelor degree in mechanical engineering from Srinakharinwirot University in Bangkok in 1996. Subsequently, he worked in Teijin Thailand Co.Ltd. for two years.(1996-1998).

Since1998, he has been working at Rajabhat Institute Petchburiwittayalongkorn as a lecturer. His work experience at Teijin Thailand Co.Ltd. encouraged him to persue his masters studies in Environmental Engineering at Suranaree University of Technology (SUT) in 1999.