THE STUDY OF CLOSE-COUPLED VERSUS UNDERFLOOR CATALYST EMISSION FOR PROTON PERSONA 1.6cc

MUHAMMAD SYAMIRUL IKHWAN BIN ZAIRULLIZAM

A thesis submitted
in fulfilment of the requirement for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled ‘The Study of Close-Coupled versus Underfloor Catalyst Emission for Proton Persona 1.6’ is the result of my own research except as cited in the references. The thesis has not been accepted to for any degree and is not currently submitted in candidature any other degree.

Signature : ....

Name : ....

Date : ....

DEDICATION

To my beloved parent and for those who are always supporting me.

ABSTRACT

Time taken to activate catalytic converter of a car has been topic of interest for researcher due to stringent emission regulation. As many years pass through, the time taken for catalytic converter to activate has reduced as the discovery of various technological advancement especially in the era of Industrial Revolution 4.0. One of the technologies that led to improvement of heating on temperature of catalytic converter is by adding a heating element of the exhaust system called 'Electrically Heated Catalyst'. This technology has been patented and been used on supercar, but not on ordinary vehicle due to cost constraint. This study will involve on the feasibility study of how fast it will heat the catalytic converter, the temperature before and after the installation of electric heated catalyst. The measurement of emission and temperature with or w/out EHC and EHC with air injection system will be recorded and analysed. The expected result would show how efficient this configuration in eliminating the initial time delay for catalyst light off. Based on result obtained, baseline HC emission measurement (without EHC and air injection) for close-coupled catalyst is better than baseline reading for underfloor catalyst, recorded its peak value at 270ppm at first 25 seconds and lowest value is recorded at 12ppm after 450 seconds for HC. While for underfloor catalyst, highest value of HC is recorded at 680ppm during the first 10 seconds and lowest value obtained is 147ppm at 380 seconds operation. For baseline CO emission reading, highest value obtained from close couple catalyst is 4.46% at the first 20 seconds and lowest value of 0.03% at 450 seconds operation. For emission reading with application of EHC and air injection, number of emission is reduced to 141ppm for HC and 6.4% for CO at 130 seconds operation.

ABSTRAK

Jumlah masa yang diperlukan untuk mengaktifkan penukar pemangkin kereta telah menjadi topik hangat para penyelidik oleh kerana peraturan pelepasan gas dari kenderaan yang telah diperketatkan. Sejak bertahun lalu, masa yang diperlukan untuk penukar pemangkin beroperasi semakin berkurangan dengan penemuan pelbagai kemajuan teknologi masa kini terutamany adalam era Revolusi Industri 4.0. Antara salah satu teknologi yang mampu meningkatkan suhu pada penukar pemangkin adalah dengan menggunakan teknologi pemangkin pemanas elektrik. Teknologi ini telah diguna secara meluas pada kenderaan berkuasa tetapi tidak digunakan pada kenderaan harian biasa akibat daripada kos pembuatan yang mahal. Kajian dalam projek ini melibatkan berapa cepat masa yang diperlukan penukar pemangkin untuk mencapai suhu ia bertindak tanpa atau dengan adanya penggunaan pemangkin pemanas elektrik pada kereta. Gas yang terhasil dari kereta tanpa atau termasuk pemangkin pemanas elektrik akan direkod dan dianalisis. Jangkaan keputusan dalam projek ini akan memaparkan kadar kebolehupayaan pemangkin pemanas elektrik dalam menghapus kelewatan penukar pemangkin untuk berfungsi sepenuhnya. Berdasarkan bacaan yang diperoleh, pengukuran pelepasan HC (tanpa EHC dan suntikan udara) untuk pemangkin rapat (CCC) adalah lebih baik daripada bacaan bacaan untuk pemangkin bawah lantai (Underfloor catalyst), mencatatkan nilai tertinggi pada 270ppm pada seawal 25 saat operasi dan nilai terendah dicatatkan pada 12ppm selepas 450 saat operasi. Untuk pemangkin bawah lantai, nilai tertinggi HC direkodkan pada 680ppm dalam tempoh 10 saat pertama dan nilai terendah yang diperoleh ialah 147ppm pada 380 saat operasi dijalankan. Untuk bacaan pelepasan CO asas pula, nilai tertinggi yang diperolehi daripada pemangkin pasangan rapat ialah 4.46% pada 20 saat pertama dan nilai terendah 0.03% pada 450 saat dijalankan. Untuk bacaan pelepasan dengan penggunaan EHC dengan suntikan udara, jumlah pelepasan dikurangkan kepada 141ppm untuk HC dan 6.4% untuk CO pada operasi 130 saat.

ACKNOWLEDGEMENT

Firstly, I would like to express my deepest appreciation to all those who provided me the possibility to complete this final year project. A special gratitude I give to my final year project supervisor, Professor Madya Dr. Noreffendy Bin Tamaldin, whose contribution in providing suggestions and encouragement, helped me to coordinate this project especially in writing this report.

Then, I would like to acknowledge much appreciation the role of the technicians, namely En. Izwan, En. Nasir and En. Asjufri who gave the permission to use all equipment required and other necessary tools to complete this project. A special thanks to my team mate, Raja Nazirul Mubin who helped me to assemble what is required to and ensure this project is finished. Finally, I would like to express my appreciation to my parent who always give full support for me to complete this project.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION AND SYMBOL

No	Abbreviation/Symbol	Meaning
1	EHC	Electric Heated Catalyst
2	ECU	Electronic Controller Unit
3	DOHC	Double Over Head Cam
4	cc	Cubic centimetre
5	kW	Power, in kilowatt
6	HP	Power, in horsepower
7	Nm	Torque, in Newton meter
8	CVT	Continuous Variable Transmission
9	HC	Hydrocarbon
10	CO	Carbon Monoxide
11	O_2	Oxygen
12	°C	Temperature, in Celsius
13	ppm	Part per million
14	CCC	Close-coupled Catalyst

CHAPTER 1

1. INTRODUCTION

1.1. Project Background

To meet the future emission standard that structured by the international organisation, a modified catalytic converter is needed to achieve emission effectiveness produced by vehicles on the road. As the number of cars are increasing year by year, the rate of pollution in the air is reaching at critical level. As has been mostly discussed in the past, the heated catalytic converter seems to be the best solution to attain standard regulation of vehicle's emissions.

The usage of electrically heated catalyst is widely used in a high-performance car while in normal, daily-drive car the technology is not applied. In 1995, Alpina, a performance company for BMW model had introduced the first model of electric heated catalyst. This technology can be found on one of their model, Alpina B12 and can be found also in Toyota MRR2. For now, it is believed that most of average car on the road in not equipped with this technology. Thus, it is a satisfactory solution to equipped this electrically heated catalyst in a normal car because this kind of car is the most seen on the road.

Figure 1.1: Alpina B12

Although the development of electrically heated catalyst shows great result especially in vehicles emissions, but the durability and electrical energy required are still lacking. Researchers had run many years of test and experiment to make the heating element more reliable.

Catalytic converter is a device that control exhaust gas emission. Internal combustion engine produces a high pollution gas but with the aided of catalytic converter, it converts the gases into a less polluted gases. Catalytic converter is used and fitted in a car to comply with standard regulation of emission. This catalytic converter is equipped for both petrol and diesel engine cars.

Years by years, researcher has find so many ways to improve the catalytic to meet emission standard regulation. One of it is by installing an electric heater catalyst on the exhaust system and most of the catalyst is installed before the engine gas flow enter the catalytic converter. Electric heated catalyst is seeming to be a new way to overcome emission problem especially during cold-start. The electrified heating element will be powered either by secondary battery or just using the available resources. Temperature of the exhaust system in the early stage of cold stage will be higher than the temperature of exhaust system that is not equipped with this electric heated catalyst. Bear in mind that this kind of technology is only applicable for high-end cars and not in normal daily cars that people drive. Thus, the idea to equip this technology into average car is good and brilliant idea.

1.2. Problem Statement

The concern about environment pollution has driven people or organization about global warming and harmful effect of gases. This has pushed researcher to make invention that will help to reduce pollution of air. Cars is main the reason that air is polluted. Many years pass through, number of cars on the road keep increasing which by means may affect the quality of air because the gases that it produces.

During cold start, cars produces high pollution of gases and one of the gas is hydrocarbon. The reason of the high level of hydrocarbon is due to the catalytic converter that yet is not activated. For average car, it took at least 4 and a half minutes to activate it because in the early when the engine is started, the temperature of the exhaust system is low, and the catalytic converter is not working yet. Thus, that is the reason of why the level of gases is so high during cold start.

To solve this problem, an electric heater is created but there is another problem that need to consider, power supply. To run the electric heater, the task is to determine the least power that able to operate the electric heater and what is the most suitable power source that can be used from a car.

With the invention of this technology, it is hopefully that this technology can be equipped to normal daily car and consume less pollution to the air.

1.3. Objective

The objective that need to be achieved within this project are:

- To integrate E-Heater and air assisted injection system for emission measurement
- To design and calibrate E-Heated Catalyst and air assisted exhaust aftertreatment.
- To perform engine performance and emission measurement before and after e-heater and air injection system calibration.

1.4. Scope of Project

The scopes of project are as follow:

i. The car that will be involved in this project is Proton Persona 2016, with 1.6 litres engine.

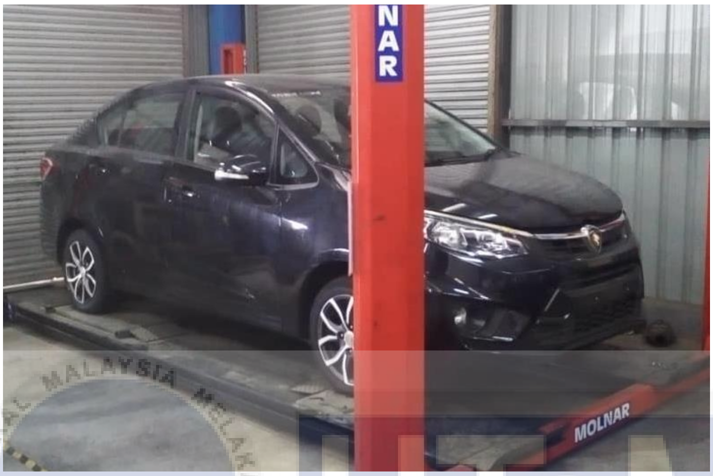

Figure 1.2: Proton Persona 1.6

ii. The electric heater is made from Emitec, model e-7710768-01.

Figure 1.3: Electric Heated Catalyst model e-7710768-01

iii. 4 unit of lambda sensors.

Figure 1.4: Lambda sensor

iv. EMS Gas Analyser

Figure 1.5: EMS Gas Analyser

v. Thermographic camera, model a655sc

Figure 1.6: FLIR model a655sc

vi. Thermocouple

Figure 1.7 : Exhaust gas Temperature Sensor Thermocouple, K Type

vii. Data logger

Figure 1.8 : Data Logger

viii. Air Injection System

Figure 1.9 : Secondary Air Injection System

CHAPTER 2

2. LITERATURE REVIEW

2.1. Catalytic Converter

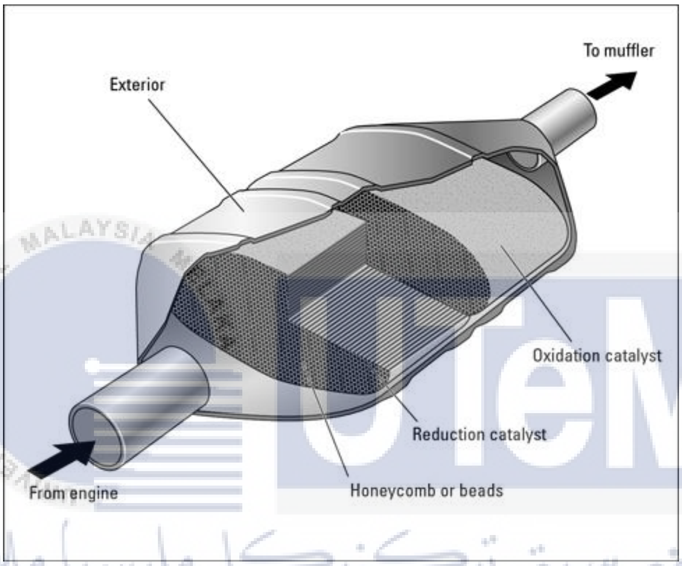

Figure 2.1: Catalytic Converter Internal

Internal combustion engine involving chemical process thus promoting air pollution. Approximately 30% of the total energy produced from engine is used to drive vehicle, 30% used by cooling system and remaining 40% released as heat through exhaust system [Su et. al 2013]. Catalytic converter is one of the efficient method, widely used in vehicles to overcome exhaust emission problem. Catalytic converter acts by converting harmful gases coming out from the engine such as Hydrocarbon (HC), Carbon Monoxide (CO), and Nitrous of Oxides (NOx) to a less harmful gases, Carbon Dioxide (CO_2), Nitrogen (N_2) and Oxygen (O_2) [Pardiwala et. al 2011]. Catalytic converter in fitted in exhaust system, between exhaust manifold and exhaust muffler. In most vehicle, they use either an underfloor three-way catalytic converter or close-coupled catalyst to reduce exhaust gas emission. Since close-coupled catalyst is positioned near with engine to reduce temperature drop while gases are flowing through the exhaust, thus close-coupled catalyst is more beneficial than underfloor three-way catalyst.

Figure 2.2: Close-coupled Catalytic Converter (Left) and Underfloor Catalytic Converter (Right)

The catalytic converter consists of 2 ceramic blocks. The first block is made from Platinum and Rhodium, Platinum and Palladium for second block. Inside catalytic converter, there are process of reduction and oxidation. Reduction process occurred on the second ceramic block while oxidation process occurred on the second ceramic block [Mukherjee et. al 2016]. Table below show conversion on gas emission through oxidation and reduction process.

Table 2.1: Oxidation process

$C_xH_{4x} + 2\times O_2$	$\rightarrow$	$xCO_2 + 2\times H_2O$
$2\times CO + O_2$	$\rightarrow$	$2\times CO_2$

Table 2.2: Reduction process

$C_xH_{4x} + 2\times O_2$	→	$xCO_2 + 2\times H_2O$
$2\times CO + O_2$	→	$2\times CO_2$
$2NO_x$	→	$N_2 + xO_2$

The activation of catalytic converter is highly depending on temperature. They will only operate when certain value of temperature is achieved. Catalytic converter can also age within time. When catalytic converter started to age with time, it will cause both reduction and oxidation process to be less react and less efficiency [Almeida et. al 2014]. Higher operation temperature of catalytic converter decreases storage capacity for oxygen and reducing conversion efficiencies, therefore, affecting its performance and increasing exhaust gas emission.

2.2. Electric Heated Catalyst

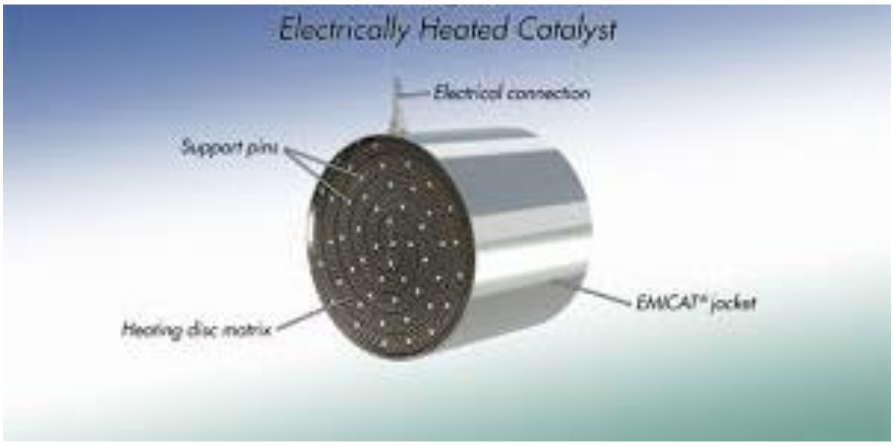

Figure 2.3: Electric Heated Catalyst

Electric Heated Catalyst (EHC) is a technology used widely in modern vehicle to overcome cold start emission issue. EMITEC, a company that produce electric heated catalyst claimed their product size can be reduced to 30% without affecting its performance and efficiencies. Electric Heated Catalyst is basically a heater, placed just before the main catalytic converter to increase exhaust temperature by providing additional heating element to the exhaust. Placing the EHC on the inlet of catalytic converter is more effective than positioned the EHC after the catalytic converter [Mianzarasvand et. al 2017]. The electrically aided heating catalyst provide efficient ways to increase directly exhaust gas temperature in the catalytic converter [Presti et. al 2013]. The EHC produces different level of energy, depending on its size or amperage. Similar temperature can be achieved between exhaust with EHC and exhaust without EHC by reducing the energy of the EHC [Presti et. al 2011].

The operation of EHC only uses a brief time, between 20 seconds to 45 seconds as it can draw too much power from the battery, draining the battery capacity. After 20 seconds operation of EHC, temperature achieved reaches over 500°C [Pfalzgraf et. al

1995]. Compared to conventional catalytic converter, the EHC helps to improve response time, reducing light-off temperature of vehicle [Presti et. al 2011]. Electrical energy is required to powered up the EHC. To achieve the Ultra-Low Emission Vehicle, power gained from alternator alone is sufficient to supply power to EHC [Kuper et. al 1994].

2.3. Cold Start Emission

A total of 65% of particle matter reduced during cold start [Whelan et. al 2013]. Cold start is a condition where vehicle engine is left between 12 to 36 hours at ambient temperature between 20°C to 30°C before the engine is started [Bhaskat et. al 2010]. When the engine is at cold start condition, catalytic converter does almost nothing to reduce and improve harmful gases coming out from the exhaust [Charles et. al 2013]. During this phase, high exhaust gas emission produced due to the catalytic converter does not start to oxidize both HC and CO until light off temperature of the catalytic converter started to activate is achieved. A cold start absolutely results in increased emission of HC and CO compared to those with warm engine [Iodice et. al 2014]. The cause may be due to several factors. First is during cold start, engine need a rich fuel-air mixture to compensate fuel that does not help in combustion. Second, the catalytic converter efficiency during cold start is too low. To reduce cold start emission, the EHC is required to reach its light off temperature quickly after the engine start and maintain at high temperature. [Ning et. al 2016].

An advanced engine development with fuel efficiency improved can reduce harmful gas emission emitted but however, this also lead to lower exhaust temperature [Chang et. al 2014]. Therefore, the purpose of EHC is to improve emission during cold start by providing high temperature to the catalytic converter, shortening the light off temperature period of the catalytic converter. Temperature at the inlet catalytic converter rise significantly with the application of EHC [Horng et. al 2004]. A high start temperature after three minutes soaking period resulting less than 10% increase in HC, CO and NOx per miles travelled [Reiter et. al 2016].

2.4. Exhaust gas emission

The presence of vehicles on the road are the sole reason of air pollution especially in urban area [Liu et. al 2015]. Almost all energy used in the world involving fossil fuel which emits a lot of harmful gases namely hydrocarbon, carbon monoxide, nitrogen oxides, carbon dioxide and etc [Jain et. al 2016]. If these gases are not treated properly, it can cause major pollution to the world and affecting human health and another living organism. For petrol engine, measurement of hydrocarbon and carbon monoxide should be prioritized since they are more dangerous as compared to other gases and HC measurement is higher for petrol engine.

2.4.1. Hydrocarbon

Hydrocarbon refers to molecules containing carbon and hydrogen as their foremost forms. Hydrocarbon may cause harmful effect to the environment such as promote cancer cells in mammals and damaging bone marrow. For most petrol engine, number of hydrocarbon emits is higher compared to other gases. Over 80% of unburnt in petrol engine are produced during cold start engine operation at ambient temperature of 20°C [Amini et. al 2014]. The value of HC is high during cold start period [Chaichan et. al 2016]. The high value of HC is due to catalytic converter is not activated. To overcome this problem, several ways are proposed and one of the solution is by implementing electric heated catalyst on the exhaust system.

With implementation of EHC, it is seen that number of HC is lower as compared to number of HC without implementation of EHC [Sendilvelan et. al 2016]. A significance drops of 65% HC obtained from catalytic converter with EHC [Charles et.

al 2013]. Result of HC shown for catalytic converter with EHC and air injection is even lower than catalytic converter with EHC only [Senidivelan et. al 2016].

2.4.2. Carbon Monoxide

Air pollution emitted from gasoline engine are coming from various form, HC, NOx and CO [Sagna et. al 2017]. CO stands for carbon monoxide, colourless and invisible with raw eyes. Carbon monoxide may cause headache, dizziness, weakness, upset stomach, vomiting, chest pain and confusion.

Value of CO emits from engine is high especially during cold start condition. A total reduction of 12.5% CO is gained from cold start for catalytic converter with EHC and 27.5% reduction of CO is obtained for catalytic converter with EHC and air injection [Bhaskar et. al 2010]. [Mianzarasvand et. al 2017] also indicates that at 35 seconds heating phase of EHC, the catalytic converter is fully operated and reach its high reaction rate but however, there is slight reduction of CO conversion after 45 seconds the heater is turned off.

2.4.3. Nitrogen of Oxides

Oxides of nitrogen are combination of gases that consist of nitrogen and oxygen. The most compound that can be found are nitric oxide (NO) and nitrogen dioxide. These gases can also be found in engine combustion.

NOx is not a big concern during cold start condition due its behaviour which are lower combustion temperature and rich fuel-air mixture. The application of EHC make no major changes in reducing the NOx, either with air injection system or with no air injection system [Coppage et. al 2001]. Therefore, there is minimal changes in NOx even with calibration of EHC and EHC with air injection system [Pfalzgraf et. al 1995].

2.5. Air Injection System

Air injection system is required to reduce exhaust gas emission during cold start phase. Purpose if air injection system is to promote oxidation process, therefore providing heat to the catalytic converter. Since heat produced increasing oxidation process, it will produce high temperature and shortening light-off temperature for catalytic converter [Sendilvelan et. al 2016].

Additional air injected into catalytic converter will acts as heating element, improving reaction inside catalytic converter and making unburnt HC reacts quickly with oxygen. With aid of air injection system, light off temperature period can be shortened [Bhaskat et. al 2010]. A total 65% reduction of HC and CO can be achieved with configuration of catalytic converter and air injection system [Bhaskar et. al 2010]. [Sendilvelan et. al 2016] also improve that number of HC and CO reduce significantly due to increasing in oxidation process with presence of high temperature.

CHAPTER 3

3. METHODOLOGY

3.1. Flow chart

Chart below shows the overall flow along period of this project:

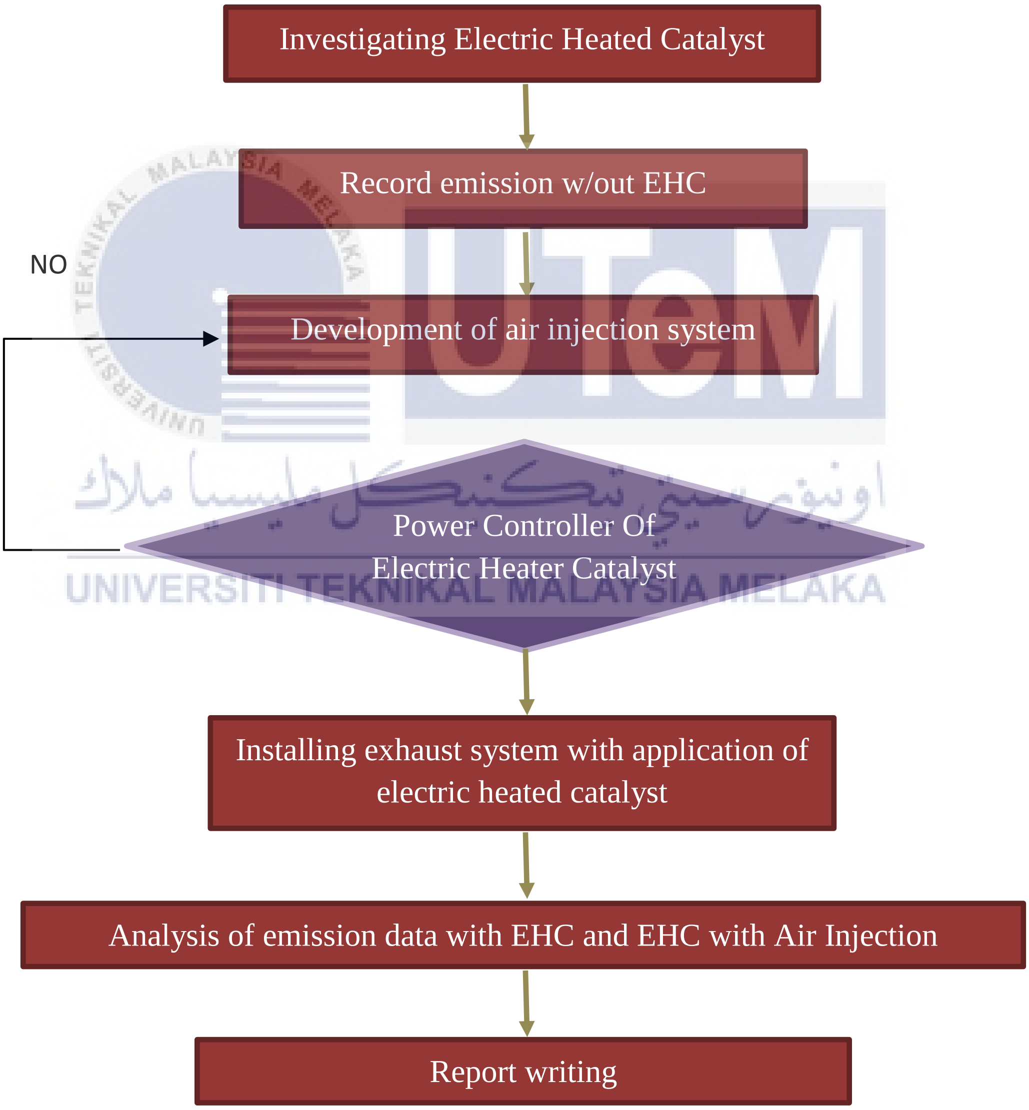

Figure 3.1: Flow Chart

3.2. Gantt Chart

	PSM 1														
	Week														
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Electric Heated Catalyst(EHC)															
Searching for Equipment to Test EHC															
Investigate minimum power needed for EHC															
Emission															
Installation of Thermocouple on Exhaust Header															
Collecting Emission Data w/out EHC															
Report															
Finding Journal															
Preparing Progress Report Chapter 1															
Submission of Progress Report Chapter 1															
Preparing Progress Report Chapter 2															
Submission of Progress Report Chapter 2															
Preparation Slide for Presentation															
Final Year Project Presentation															

Planned Activity

Actual Task

Task met schedule

	PSM 2														
	Week														
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Electric Heated Catalyst(EHC)															
Searching equipment for dyno test															
Dealing with supplier															
Fabrication and modification of exhaust system															
Emission															
Installation of Thermocouple on Exhaust Header															
Collecting Emission Data with EHC and secondary air injection system															
Report															
Preparing Progress Report															
Submission of Progress Report Chapter 1															
Preparing Progress Report															
Submission of Final Report															
Preparation Slide for Presentation															
Final Year Project Presentation															

3.3. Experimental Method

There are several methods planned to run this experiment. The methods of experiment are listed as below:

3.3.1. Testing Electric Heater Catalyst

The task is to investigate what is the minimum power required to function the electric heated catalyst. An AC machine will be used to regulate voltage to find the minimum working voltage for EHC to operate. A thermographic camera will be used to detect heat that created after electric power is supplied to the EHC.

At first, the Electric Heated Catalyst will be clamped on a retort stand. The EHC later will be connected to the AC machine by using cables. It is compulsory to ensure the cable that being used is good enough to support power because if not, the cable will be burnt. Then, thermographic is positioned parallel with the EHC within suitable range. Below is the setup for measuring temperature of the EHC:

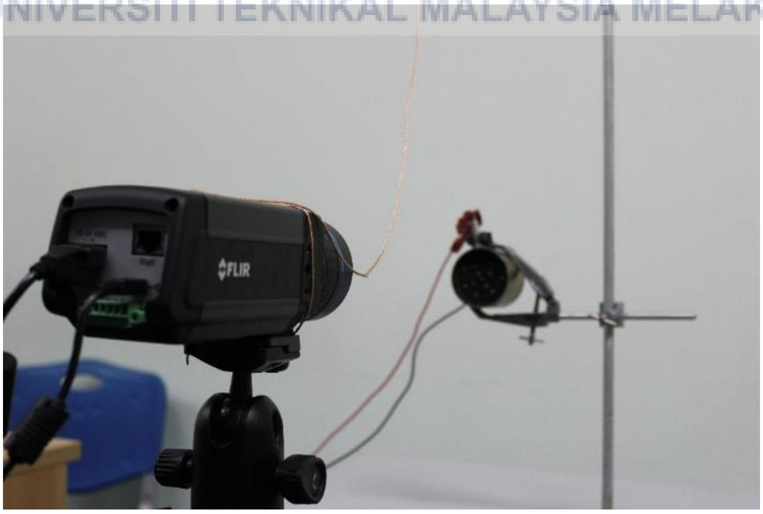

Figure 3.2: thermographic camera must be aligned parallel with EHC

Figure 3.3: An AC machine will be connected to EHC. The temperature will be recorded by computer.

The test will be started with the least voltage that enable the EHC to operate. Once the EHC activated, temperature of it is measured by using the thermographic camera. The experiment is then conducted repeatedly with variation of voltage supply.

3.3.2. Emission Test Before Installation of EHC

The reason to conduct this experiment is to differentiate whether if the installation of EHC create better result in term of emission. An EMS, a gas analyser machine will be used to measure exhaust gases emission and exhaust temperature. In this case, a thermocouple is installed first at position before exhaust gas flow into catalytic converter. All data emission such as hydrocarbon, oxygen and oxides of nitrogen will be recorded.

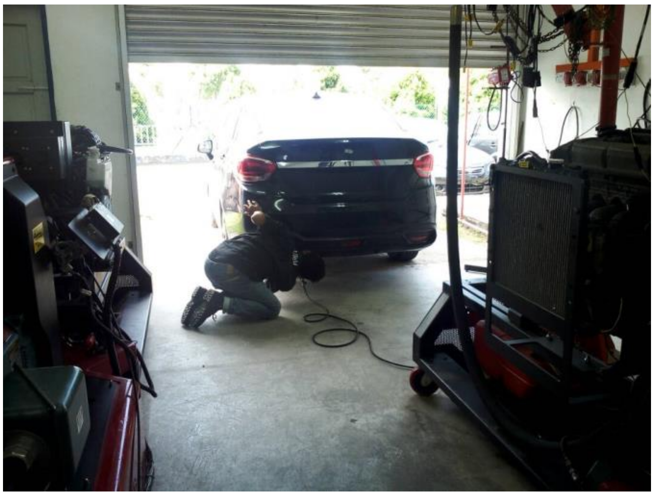

Figure 3.4: Installing gas probe into exhaust muffler

Detailed below shows the specification of proton Persona 1.6, 2016 model.

Table 3.1: Proton Persona 2016 Specification

Proton Persona 2016 Specification	
Engine Type	1.6L 4-cylinder DOHC
Bore × Stroke (mm)	76 × 88
Total Displacement	1597cc
Compression Ratio	10
Maximum Power (kW(HP)@rpm)	80(107) @ 5750rpm
Maximum Torque (Nm@rpm)	150@4000
Fuel Consumption (L/100km)	6.1
Transmission	CVT Automatic
Kerb Weight (kg)	1175

3.3.3. Fabrication and Modification of Exhaust System

In this section, the task is to modify the current exhaust system by replacing current close-coupled catalyst to underfloor catalyst to ensure the electric heater catalyst can be fit into the exhaust system, just before the main catalytic converter. To measure exhaust temperature, 4 sets of thermocouples is required and positioned at 4 different places. The position of the thermocouple is shown in figure 18. In this section also requires drilling other holes to fit air injection system into the exhaust. The usage of air injection system is to provide and inject additional air to the exhaust. Position of air injection system also shown in figure 18. Table 4 show the specification for air injection system.

Table 3.2: Air Injection Specification

Voltage	220 - 240V
Frequency	50/60Hz
Power	1.5W
Max. output	1.6L/min

Figure 3.5: Figure above show welding a nut(left) after hole is drilled and installation of EHC with the exhaust manifold and catalytic converter

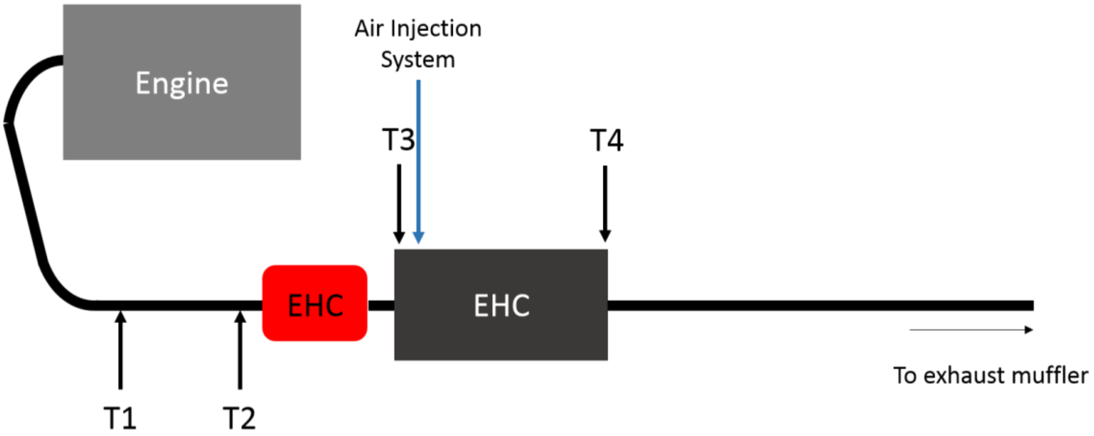

Figure 3.6: Schematic diagram of thermocouple position

3.3.4. Power Controller System of Electric Heated Catalyst

The Power Controller System consist of a system to power up the Electric Heated Catalyst. This system also will require a few electronic equipment. The equipment is listed as below:

- 12 Volts Battery – acts as power source
- On Switch – System only operated if this switch is switched on
- Timer Switch – System operated at certain period.
- Starter Relay – Provide high current to heater
- Latching Relay – To bypass push button on switch.

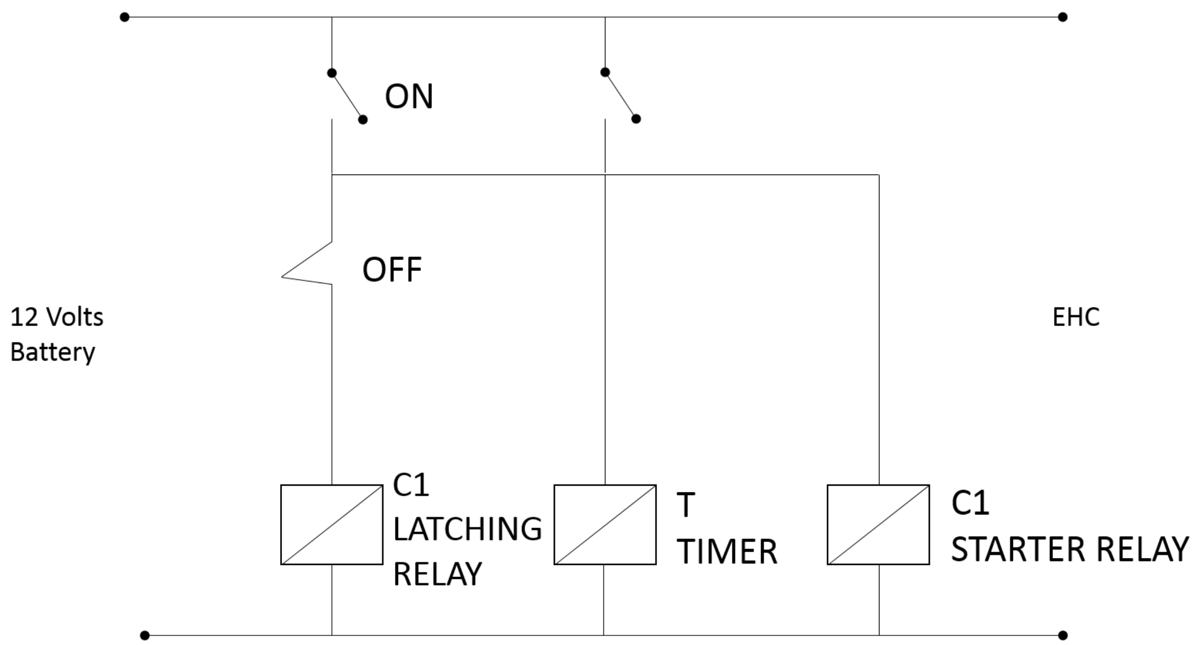

Figure 3.7 : Schematic Diagram for Power Controller System

3.3.5. Calibration of Thermocouple

Thermocouple purpose is to detect heat signature in the exhaust flow. Once the thermocouple senses the heat, it will translate the data to the computer through data logger system. To do so, the thermocouple will first have connected with the data logger and data logger will be connected to the computer. Data measured will be analysed by its data logger software called PicoLog Recorder.

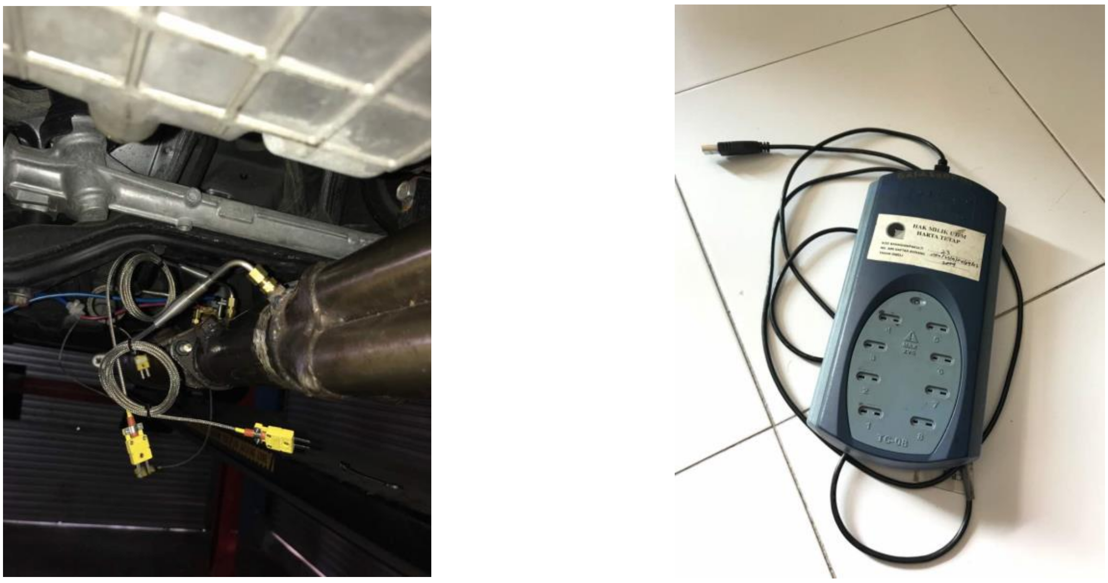

Figure 3.8: Thermocouples are fitted into exhaust (left) and data logger system (right)

3.3.6. Emission test with EHC and air injection system

Figure 3.9: Conducting emission test with EHC and air injection system

After the fabrication of the new exhaust system and calibration of thermocouple is complete, the next phase is to continue with gas emission testing with implementation of EHC and air injection. In this test, all emission gases such as HC, CO, NOx, CO_2

and O_2 are recorded. Also recorded is exhaust temperature at decided position. Data obtained will then compared with emission data for catalytic converter without the implementation of EHC and air injection system.

CHAPTER 4

4. RESULT & DISCUSSION

To study the effect of electrically heated catalyst toward exhaust emission produced, there are several kinds of experiment conducted. In all experiment, the parameter need to investigate is exhaust gas emission such as HC, CO, and O_2 and measuring the exhaust gas temperature. The first experiment is investigating the baseline measurement of originally closed couple catalyst behaviour of the car and continue with underfloor catalytic converter. Then, measurement of underfloor catalytic converter with electric heated catalyst and underfloor catalytic converter with electric heated catalyst and secondary air injection system are recorded.

4.1. Data Analysis for Gas Emission & Temperature w/out EHC at idle. (Close-coupled Catalyst)

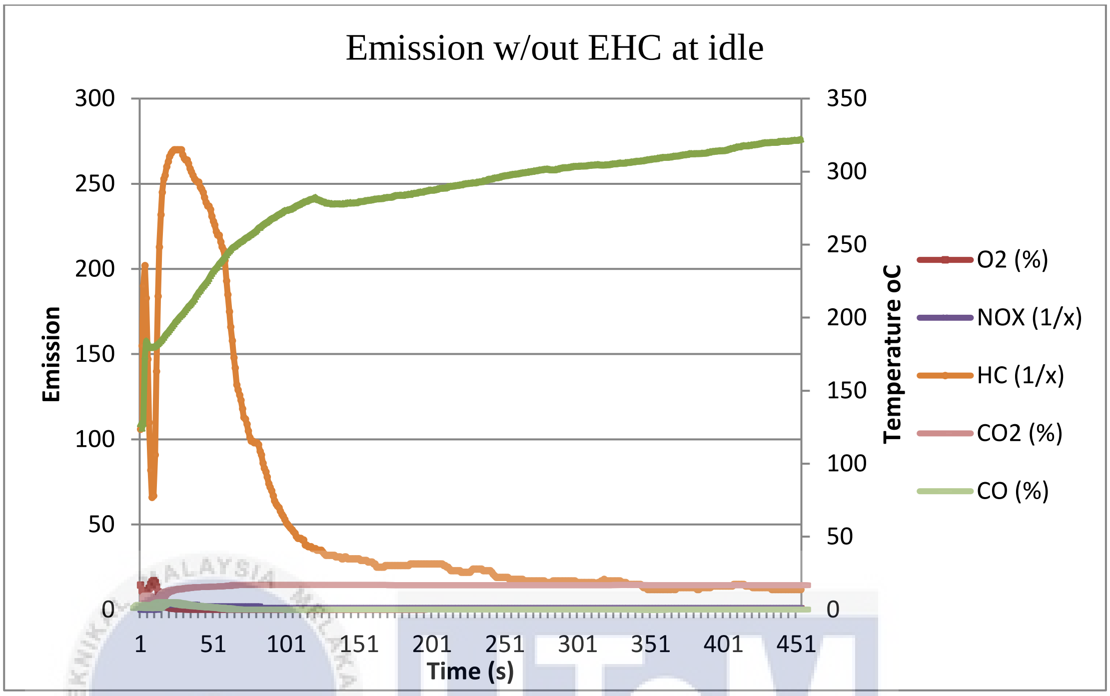

Figure 4.1: Graph of Emission w/out EHC at idle

Figure 4.1 shows variation of gas emission and exhaust gas temperature collected without the implementation of Electric Heated Catalyst with the car is at idling condition for close-coupled catalyst. Before the test started, the car was left switched off, at least 12 hours before the experiment was conducted to meet cold start condition.

Once the engine started, the peak number of HC gained from the test is higher as compared to other gas emission, reaching approximately 270ppm at the first 25 seconds of the test. Also, at 25 seconds, approximately 3ppm of NOx number, 12% of CO_2, CO of 4% and 0.7% of O_2 was recorded. When time reaches approximately 440 seconds, the emission gases started to drop and stabilize, recorded at 12ppm for HC, 1ppm for NOx, 14.4% for CO_2, 0.03% for CO and 0.72% for O_2, indicating that the catalytic converter start to activate and occurred when temperature is operating at approximately 280°C.

4.2. Data Analysis of Gas Emission & Temperature w/out EHC at 2000rpm. (Close-Coupled Catalyst)

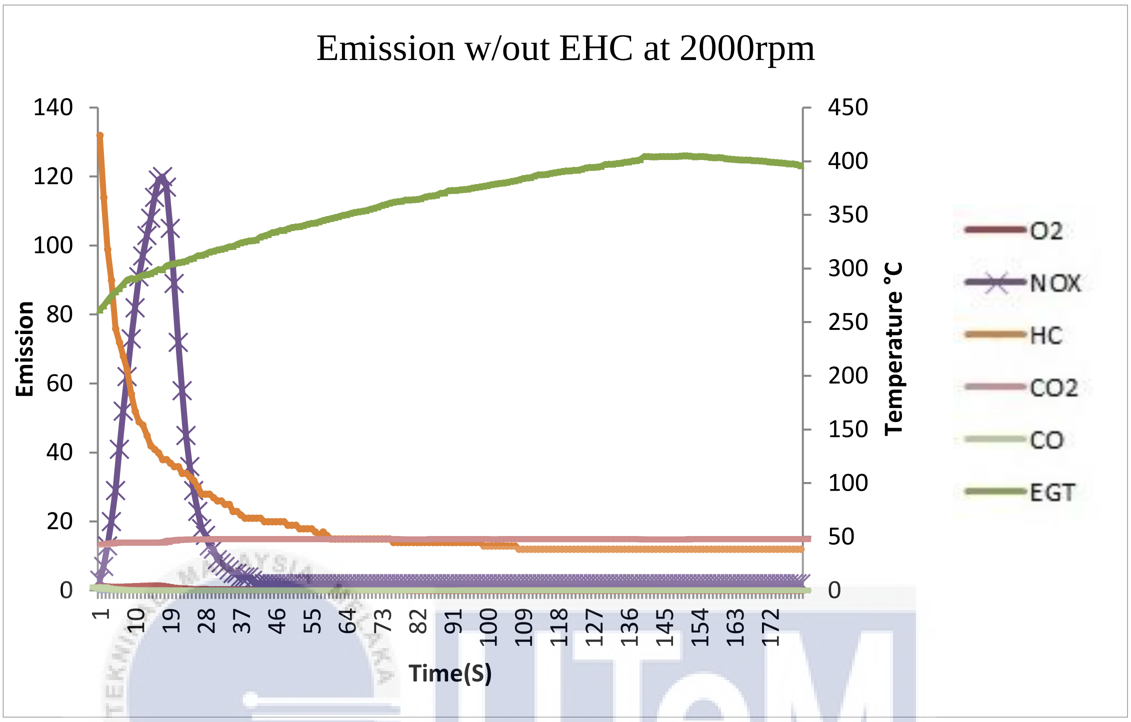

Figure 4.2: Emission w/out EHC at 2000rpm

Since the test was run at 2000 rpm, it produces higher temperature even when the car was switched-on for first 10 seconds. Therefore, number of HC produced in this test is recorded at 10 seconds, approximately 50ppm, lesser than idle condition. In similar period, approximately 91ppm of NOx number, 14% of CO_2, CO of 0.06% and 1.2% of O_2 was recorded. When time reaches approximately 20 seconds, all emission gases started to drop gradually with time, result obtained shows 12ppm is recorded for HC, 2ppm for NOx, 14.9% for CO_2, 0.03% for CO and 0.19% for O_2, at operation temperature of 382°C.

4.3. Data analysis of Gas Emission & Temperature w/out EHC at idle (Underfloor Catalyst)

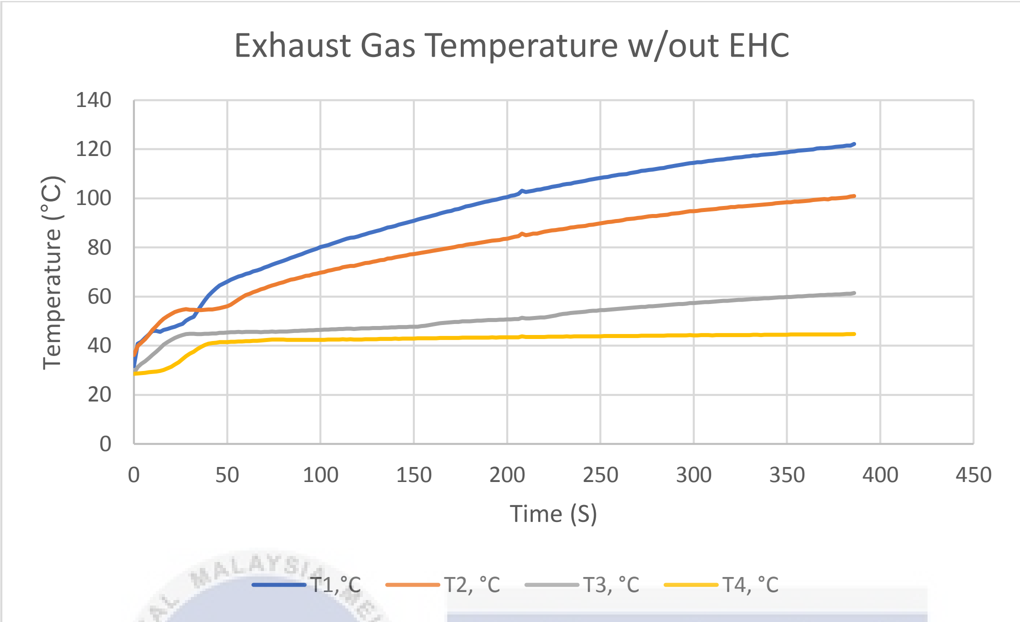

Figure 4.3: Exhaust Gas Temperature (Underfloor Catalyst)

Figure above shows exhaust gas temperature at idle condition without the presence of electric heated catalyst. From the graph, temperature 1, T1 has the highest temperature reading, recorded at 120°C at 300 seconds of operating due to its position that is near with the engine. Within the same period, Temperature 2, T2 comes in second highest, recorded at 100°C since its position is located second nearer with the engine and followed by temperature 3, T3 at 60°C and Temperature 4, T4 at approximately 45°C.

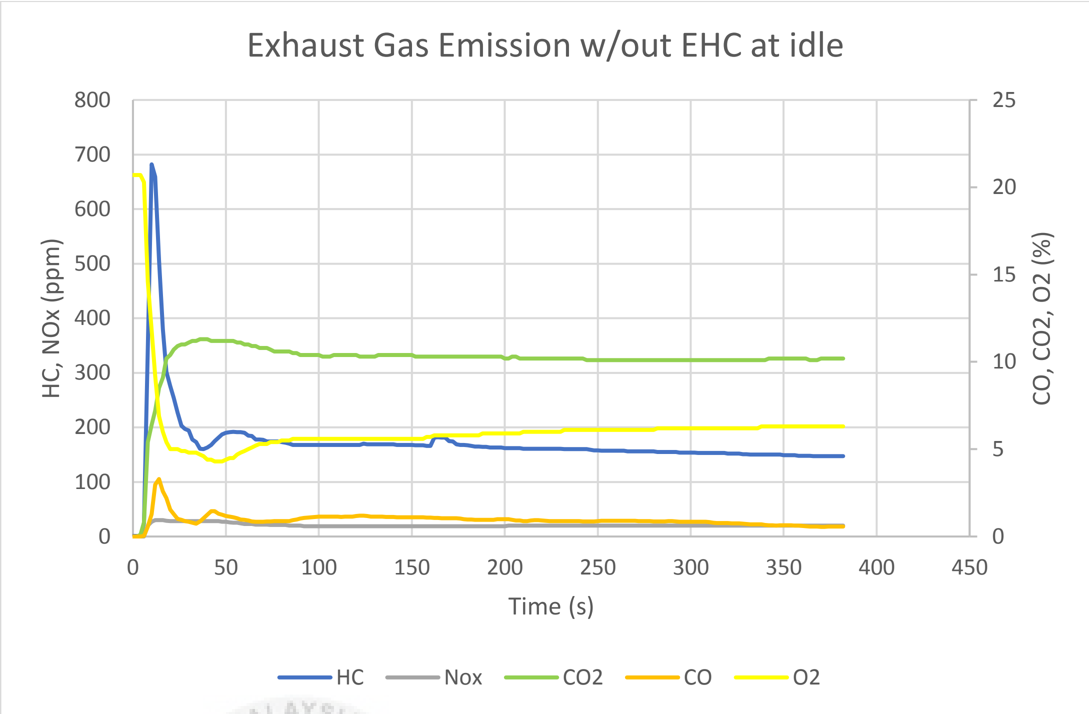

Figure 4.4:Exhaust Gas Emission (Underfloor Catalyst)

Figure above shows variation of exhaust gas emission produced by underfloor catalyst without the electric heated catalyst installed. The engine is left at room temperature before operating the test to meet cold start condition requirement.

During test, once the engine started, number of exhaust emission increase gradually with time especially HC. Value of HC obtained is greater compared to other gas emission, reaching approximately 680ppm for the first 10 second of the engine switched on. The number of HC gained in this test is far greater as compared to number of HC obtained from closed-couple catalyst at idle condition. In similar period, approximately 30ppm of NOx number, 6.4% of CO_2, CO of 1.3% and 11.8% of O_2 was recorded. When time reaches approximately 370 seconds, all emission gases started to drop and maintain, number of HC is recorded at 147ppm, 20ppm for NOx, 10.2% for CO_2, 0.56% for CO and 6.3% for O_2.

4.4. Data Analysis of Gas Emission & Temperature with EHC + Air Injection System at idle (Underfloor Catalyst)

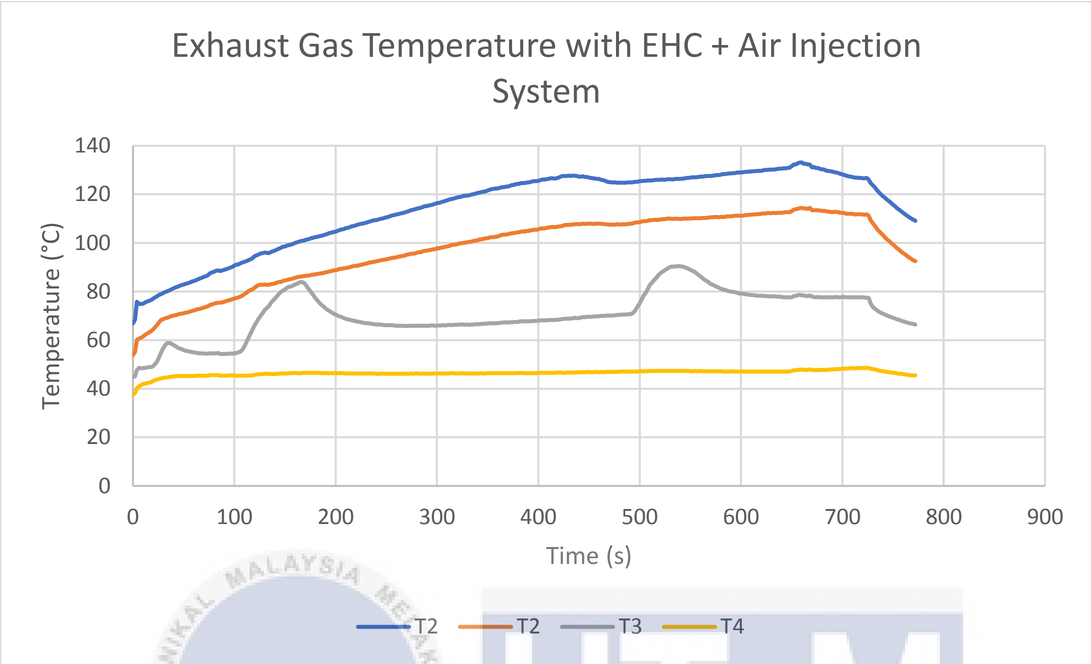

Figure 4.5: Exhaust Gas Temperature with EHC + Air Injection System

Figure above shows exhaust gas temperature with electric heater catalyst installed and additional air injection system positioned on the exhaust system. Temperature 1, T1 recorded the highest as compared to others due to its position near with engine. When EHC is switched on between period 100 seconds to 160 seconds, temperature at T3 increase faster compare to condition at which the EHC is switched off. At period of 160 seconds, T3 (Position which air is injected) is recorded at approximately 70°C, higher that condition without EHC switched on (recorded at 50°C). At 160 seconds of the test with EHC switched on, approximately 105°C is recorded at T1, 88°C at T2 and 46°C at T4. After 160 seconds of operation, EHC is switched off without turning off the injector. Result, temperature at T3 started to decrease again since the air injected to that location is cooling down the temperature of that area.

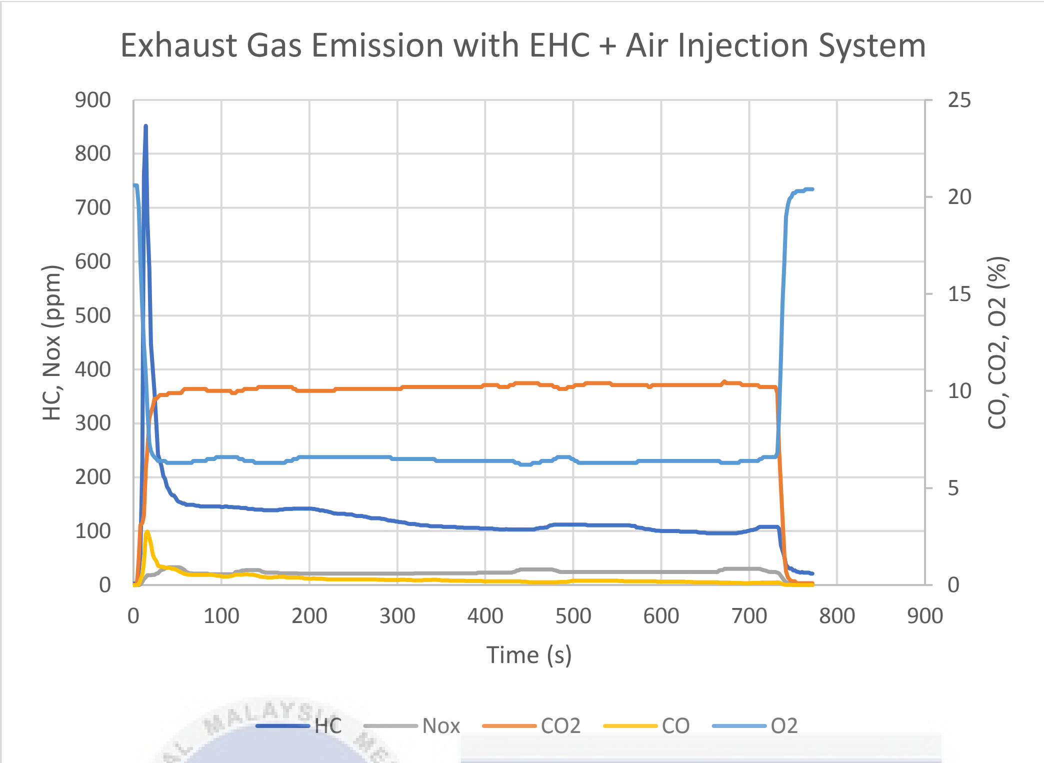

Figure 4.6: Exhaust Gas Emission with EHC + Air Injection System

Figure above shows variation of exhaust gas emission produced by underfloor catalyst with the electric heated catalyst installed and additional air injection system. The EHC can only be operated at certain period since it consumes too much power and may drain power from the car's battery.

Once the engine started, number of gas emission increase gradually, mainly HC. Number of HC during the first 15 seconds achieves approximately 700ppm and then after 15 seconds of operating, number of HC decrease gradually with time, same goes to other gas emission.

When the test is reaching at 130 seconds, the condition where the EHC is switched on and extra air is injected into the exhaust, numbers of HC has reduces, recorded to be 141ppm, 28ppm for NOx, 10.1% for CO_2, 0.55% for CO and 6.4% for O_2 and are still dropping with average reaction rate with temperature of 73°C is recorded at T3 (Position which air is injected). But when EHC is switched off while injector continue supplying air into exhaust system at period of 160 seconds, temperature recorded at position T3 slightly decrease, causing the number of HC increase, recorded at approximately 142ppm. But again, after certain period, number of HC decreases gradually with time even without the operational of EHC. At period of 520 seconds of operation, both EHC and air injector are switched on again and number of HC obtained is recorded at 111ppm, 24ppm of NOx, 10.4% of CO_2, .023% of CO and 6.3% of O_2 and decreasing. Sudden increase of oxygen after 720 seconds of operation is due to engine was switched off while the injector stays switched on. Number of HC reaches its lowest value at 108ppm after 12 minutes of operation. In similar period, NOx is recorded at 26ppm, 10.2% for CO_2, 0.12% for CO and 6.3% for O_2. Compare to baseline reading, value and percentage of HC and O_2 is slightly higher but significance drop in CO value.

CHAPTER 5

5. CONCLUSION AND FUTURE STUDY

High temperature is required to allow any catalytic converter working efficiently. The presence of EHC and air injection system able to reduce exhaust gas emission and exhaust temperature but result obtained is not too significance as compared to closed-couple catalyst.

Number of HC produced for underfloor catalyst with EHC and air injection system reduce but the efficiencies is not as great as result obtained from closed-coupled catalyst. The purpose of supplying secondary air to the exhaust is to provide another flammable element, oxygen into the exhaust but result obtained show no significance reduction of HC. Instead, additional supplied air acts as cooling element, reducing exhaust temperature.

The application of EHC and air injection system in a high-performance car may show positive result in reducing exhaust gas emission especially during cold start condition but in this experiment, result obtained on a small engine displacement shows the opposite due to difference parameter in term of compression ratio and temperature produce from the engine. This experiment also conclude that the performance of close-coupled catalyst shows better result compare to underfloor catalyst equipped with EHC and air injection system. Thus, the usage of electric heated catalyst and air injection system may not too suitable to be applied into a small engine displacement vehicle.

For future study, there are several ideas proposed to enhance the electric heated catalyst system. The first idea is the usage of renewable energy, such as solar panel to use as source of power to operate the electric heated catalyst. The second idea is using improved electric heated catalyst that only uses low power to avoid car's battery from draining. Last, investigating technologies used in Formula 1, Kinetic Energy Recovery System (KERS) to be applied to electric heated catalyst as its source of power. The energy is generated from waste energy create when braking. During braking, a lot of heat produced due to friction and the energy will then converted into electrical energy.

REFERENCES

Advantages of METALIT Catalyst. Available at : http://www.emitec.com/en/technology/catalyst-substrates/metalitr-catalysts/

All New Proton Persona retrieved from https://www.google.com/search?biw=1360&bih=662&tbm=isch&sa=1&ei=3gW1WuKcPMjsvgT9ga3oAg&q=proton+persona+2017&oq=proton+pers&gs_l=psy-ab.3.2.0l10.189049.192804.0.194079.11.10.0.1.1.0.105.788.9j1.10.0....0...1c.1.64.psy-ab..0.11.793...0i67k1.0.dOl7Y8cSSQk#imgrc=YjN-ywfKfj9kDM:

Amini, M. R., Shahbakhti, M., & Ghaffari, A. (2014). A novel singular perturbation technique for model-based control of cold start hydrocarbon emission. SAE International Journal of Engines, 7(2014-01-1547), 1290-1301.

Bezaire, B. A. (2011). Modeling and Control of an Electrically-Heated Catalyst (Doctoral dissertation, The Ohio State University).

Bezaire, B., & Midlam-Mohler, S. (2012). A Physically-Based, Lumped-Parameter Model of an Electrically-Heated Three-Way Catalytic Converter (No. 2012-01-1240). SAE Technical Paper.

Bhaskar, K., Nagarajan, G., & Sampath, S. (2010). Experimental investigation on cold start emissions using electrically heated catalyst in a spark ignition engine. International Journal of Automotive and Mechanical Engineering, 2(1), 105-118.

BMW Alpina B12 retrieved from https://www.google.com/search?q=alpina+b12&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiZyLWEy4LaAhVGMY8KHQlqCZEQsAQIJw&biw=1360&bih=662#imgdii=N0qXy7UBgOeUZM:&imgrc=CQvqWmjNmPgSZM:

Carbon Monoxide effects retrieved from https://www.cdc.gov/co/faqs.htm

Catalytic Converter : How it Work retrieved from https://www.youtube.com/watch?v=lJiznlz5buc

Chaichan, M. T., Marhoon, O. K., & Mohammed, B. A. (2016). The effect of spark ignition engine cold starting period on emit-ted pollutants. Sci Eng Rep, 1(1).

Charles, X., Parta, S. C., & Nallusamy, K. S. (2013). Use of electrically heated metal catalytic converter in cold starting to reduce automotive emissions. Science, Technology and Arts Research Journal, 2(3), 147-152.

Coppage, G. N., & Bell, S. R. (2001). Use of an electrically heated catalyst to reduce cold-start emissions in a Bi-fuel spark ignited engine. Journal of engineering for gas turbines and power, 123(1), 125-131.

de Almeida, P. R., Nakamura, A. L., & Sodré, J. R. (2014). Evaluation of catalytic converter aging for vehicle operation with ethanol. Applied Thermal Engineering, 71(1), 335-341

Effect of Hydrocarbon on environment retrieved from https://sciencing.com/effects-hydrocarbons-environment-15879.html

Emitec, 2011. Heated Catalyst, The Solution to Future Emissions Problem. Available at : https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiz_P7yh4bYAhVIPY8KHTTIDo0QFggoMAA&url=http%3A%2F%2Fwww.emitec.com%2Ffileadmin%2Fuser_upload%2FPresse%2FPresseinformationen%2F201109_03_E_IAA_Heated_Catalyst.pdf&usg=AOvVaw2ei9IFViBPhfebaslEI66Q

Engineering Explained, 2013. Catalytic Converter-Explained. Available at : https://www.youtube.com/watch?v=HADOcrcMikA

Favre, C., May, J., & Bosteels, D. (2011). Emissions control technologies to meet current and future european vehicle emissions legislation. Association for Emissions Control by Catalyst (AECC) AISBL, Brussels, 20.

FLIR A655sc Infrared Camera retrieve from https://www.google.com/search?biw=1360&bih=662&tbm=isch&sa=1&ei=owa1WsLjFcnivATrhaqwCw&q=FLIR+model+a655sc&oq=FLIR+model+a655sc&gs_l=psy-ab.12...121668.121668.0.122947.1.1.0.0.0.0.64.64.1.1.0....0...1c.1.64.psy-ab..0.0.0....0.DIvgW5X26Eg#imgrc=ZuWrUowVVIUUJM:

Gonze, E. V., Paratore, M. J., & Kalebjian, C. J. (2015). U.S. Patent No. 9,200,553. Washington, DC: U.S. Patent and Trademark Office.

How Does an Oxidation Catalyst Work? Retrieved from https://www.nettinc.com/information/emissions-faq/how-does-an-oxidation-catalyst-work

Kašpar, J., Fornasiero, P., & Hickey, N. (2003). Automotive catalytic converters: current status and some perspectives. Catalysis Today, 77(4), 419-449.

Kessels, J. T. B. A., Foster, D. L., & Bleuanus, W. A. J. (2010). Fuel penalty comparison for (electrically) heated catalyst technology. Oil & Gas Science and Technology–Revue de l'Institut Français du Pétrole, 65(1), 47-54.

Khan, S. R., Zeeshan, M., & Iqbal, S. (2018). Thermal management of newly developed non-noble metal-based catalytic converter to reduce cold start emissions of small internal combustion engine. Chemical Engineering Communications, 205(5), 680-688.

Knorr, T., Ellmer, D., Maiwald, O., Schatz, A., & Brück, R. (2015). The Electric Heatable Catalyst–An Efficient Measure for Emission Optimization in Mild Hybrid Vehicle Operation Strategies. In 24th Aachen Colloquium Automobile and Engine Technology.

Küper, P. F., Maus, W., Swars, H., Brück, R., & Kaiser, F. W. (1994). Ultra-low power electrically-heated catalyst system(No. 940465). SAE Technical Paper.

Laing, P. M. (1994). Development of an alternator-powered electrically-heated catalyst system (No. 941042). SAE Technical Paper.

Lucchesi, R. P. (1994). U.S. Patent No. 5,357,752. Washington, DC: U.S. Patent and Trademark Office.

Maus, W., Brück, R., Konieczny, R., & Scheeder, A. (2010). Electrically heated catalyst for thermal management in modern vehicle applications. MTZ worldwide, 71(5), 34-39.

Mianzarasvand, F., Shirneshan, A., & Afrand, M. (2017). Effect of electrically heated catalytic converter on emission characteristic of a motorcycle engine in cold-start conditions: CFD simulation and kinetic study. Applied Thermal Engineering, 127, 453-464.

Ning, J., & Yan, F. (2016). Temperature Control of Electrically Heated Catalyst for Cold-start Emission Improvement. IFAC-PapersOnLine, 49(11), 14-19.

Nithyanandan, N., Sendilvelan, S., Bhaskar, K., Balaji, N., & Mohanamurugan, S. (2010). Exposed area influence for light off of catalyst to reducing hc/co emission from automobile SI engine exhaust by using low mass electrically heated metal catalyst. International Journal of Applied Engineering Research, 5(3), 441-448.

Oxides of Nitrogen Definition retrieved from http://www.npi.gov.au/resource/oxides-nitrogen-0

Pfahl, U., Schatz, A., & Konieczny, R. (2012). Advanced exhaust gas thermal management for lowest tailpipe emissions-combining low emission engine and electrically heated catalyst (No. 2012-01-1090). SAE Technical Paper.

Pfalzgraf, B., Otto, E., Wirth, A., Kueper, P. F., Held, W., & Donnerstag, A. (1995). The system development of electrically heated catalyst (EHC) for the LEV and EU-III legislation (No. 951072). SAE Technical Paper.

Polidoros Stavropoulos, 2016. EHCC(Electric Heated Catalyst Converter. Available at : https://www.youtube.com/watch?v=-jq2Izq606c

Pontikakis, G. N., Konstantas, G. S., & Stamatelos, A. M. (2004). Three-way catalytic converter modeling as a modern engineering design tool. Journal of engineering for gas turbines and power, 126(4), 906-923.

Presti, M., & Pace, L. (2011). An Alternative Way to Reduce Fuel Consumption During Cold Start: The Electrically Heated Catalyst. SAE International.

Presti, M., Pace, L., Poggio, L., & Rossi, V. (2013). Cold Start Thermal Management with Electrically Heated Catalyst: A Way to Lower Fuel Consumption (No. 2013-24-0158). SAE Technical Paper.

Proton Persona 2016 Model Specification retrieved from https://newcar.carlist.my/proton/2018/persona

Proton Persona 2016 Specification retrieve from http://www.proton.com/en/Find-a-Car/Persona

Proton Persona 2016 Specification retrieve from https://www.carbase.my/proton/persona/p2-21a/1.6-standard-cvt-2018

Reduction Process in Catalytic Converter. Retrieved from https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Kinetics/Case_Studies%3A_Kinetics/Catalytic_Converters

Reiter, M. S., & Kockelman, K. M. (2016). The problem of cold starts: A closer look at mobile source emissions levels. Transportation Research Part D: Transport and Environment, 43, 123-132.

Roberts, A., Brooks, R., & Shipway, P. (2014). Internal combustion engine cold-start efficiency: A review of the problem, causes and potential solutions. Energy Conversion and Management, 82, 327-350.

Roduner, C. A., Onder, C. H., & Geering, H. P. (1997). Automated design of an air/fuel controller for an SI engine considering the three-way catalytic converter in the H∞ approach. In Proceedings of the fifth IEEE Mediterranean Conference on Control and Systems, Paphos, Cyprus.

Sagna, K., Amou, K. A., Boroze, T. T. E., Kassegne, D., d'Almeida, A., & Napo, K. (2017). Environmental Pollution due to the Operation of Gasoline Engines: Exhaust Gas Law. International Journal of Oil, Gas and Coal Engineering, 5(4), 39.

Su, C., Tong, N., Xu, Y., Chen, S., & Liu, X. (2013). Effect of the sequence of the thermoelectric generator and the three-way catalytic converter on exhaust gas conversion efficiency. Journal of electronic materials, 42(7), 1877-1881.

The Electrically Heated Catalyst EMICAT Explanation. Available at : http://www.emitec.com/en/technology/catalyst-substrates/emicat/

Three-way Catalytic Converter – How Does It Work? Retrieved from https://www.youtube.com/watch?v=1e9EvrThk1Y

Whelan, I., Timoney, D., Smith, W., & Samuel, S. (2013). The effect of a three-way catalytic converter on particulate matter from a gasoline direct-injection engine during cold-start. SAE International Journal of Engines, 6(2), 1035-1045.

Yang, S. (2017). Investigation of Light-off Temperature and Conversion Efficiency of Electrically-Heated Catalyst (Doctoral dissertation, The Ohio State University).

Yi, Z., Xinyu, L., & Weimin, G. (2002). Experimental research on performance of three-way catalytic converter in engine cold start phase [J]. Chinese Internal Combustion Engine Engineering, 3, 43-45.

Zammit, M., Wuttke, J., Ravindran, P., & Aaltonen, S. (2012). The Effects of Catalytic Converter Location and Palladium Loading on Tailpipe Emissions (No. 2012-01-1247). SAE Technical Paper.

LIST OF APPENDICES