COMPARISON OF PERFORMANCE AND EMISSION CHARACTERISTICS BETWEEN CERAMIC AND METALLIC CATALYTIC CONVERTER

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ABSTRACT

Catalytic converters have been widely used on vehicles and have already been proved for many years to be the most effective technical solution to reduce exhaust emissions from gasoline engines where ceramic and metallic catalytic converters are the most common types of catalytic converter used. This study focuses to examine the performance of ceramic and metallic catalytic converters through simulation and experimental in terms of flow distribution and pollutant gases conversion. ANSYS Fluent 16.2 has been used for the simulation process and Mitsubishi 4G93 1800cc gasoline engine with difference speed and 25% constant load were used for the emission measurement using Kane Auto 5-1 series exhaust gas analyser. Simulation process has been conducted to measure pressure, velocity and temperature distribution through the ceramic and metallic catalytic converter and for the experimental process, the performances and pollutant gases conversion were recorded to compare both type of catalytic converters. Based on the simulation results, ceramic honeycomb catalytic converter shows higher pressure distribution 181.1 Pa on the inlet region compares to metallic sinusoidal. On the other hands, metallic sinusoidal catalytic converter has better velocity distribution of 14.3 ms^{-1} and temperature distribution of 1100 Kat the inlet region. Through the experimental results, metallic sinusoidal catalytic converter performs a better reduction of CO compares to ceramic honeycomb catalytic convetier while ceramic honeycomb performs better reduction than metallic sinusoidal catalytic converter for HC and NO_x conversion. It can be concluded that metallic corrugated catalytic converter has performs better flow distribution through the substrates while ceramic converters reduce a higher percentage of CO and NO_x pollutant gases.

ABSTRAK

Penukar bermangkin telah digunakan secara meluas pada kenderaan dan telah dibuktikan selama bertahun-tahun untuk menjadi penyelesaian teknikal yang paling berkesan untuk mengurangkan pelepasan ekzos dari enjin petrol di mana penukar bermangkin seramik dan metalik adalah jenis penukar bermangkin yang paling biasa digunakan. Kajian ini memberi tumpuan untuk mengkaji prestasi penukar pemangkin seramik dan logam melalui simulasi dan eksperimen dari segi pengagihan aliran dan penukaran gas pencemar. ANSYS Fluent 16.2 digunakan untuk proses simulasi dan enjin petrol Mitsubishi 4093 1800cc dengan kelajuan berbeza dan 25% beban berterusan digunakan untuk pengukuran pelepasan menggunakan penganalisis gas ekzos Kane Auto 5-l. Proses simulasi telah dijalankan untuk mengukur tekanan, halaju dan pengagihan suhu melalui penukar bermangkin seramik dan logam dan untuk proses eksperimen, prestasi dan penukaran gas pencemar direkodkan untuk membandingkan kedua jenis penukar bermangkin. Berdasarkan hasil simulasi, penukar bermangkin seramik heksagon menunjukkan pengedaran tekanan yang lebih tinggi 181.1 Pa pada saluran masuk berbanding dengan penukar bermangkin logam beralun. Di sisi lain, penukar bermangkin logam beralun mempunyai pengagihan halaju yang lebih baik dari 14.3 ms^{-1} dan pengedaran suhu 1100 K pada saluran masuk. Melalui hasil eksperimen, penukar bermangkin logam beralun menghasilkan pengurangan HC yang lebih baik berbanding dengan penukar bermangkin seramik heksagon manakala penukar bermangkin seramik heksagon menghasilkan penukaran yang lebih baik daripada penukar bermangkin logam beralun bagi penukaran HC dan NO_x. Ia dapat disimpulkan bahawa penukar bermangkin logam beralun telah melakukan pengagihan aliran yang lebih baik melalui substrat manakala penukar bermangkin seramik mengurangkan peratus yang lebih tinggi untuk gas CO dan NO_x.

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LIST OF SYMBOLS AND ABBREVIATIONS

Jc	Lambda
y-Al20J	Gamma Alumina
JD	One Dimensional
3D	Three Dimensional
3WCC	Three Way Catalytic Converter
AFR	Air Fuel Ratio *AT*
	After Treatment *BDC*
	Bottom Dead Centre
BMEP	Brake Mean Effective Pressure
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
CoO	Cobalt Oxide
CAA	Clean Air Act
CAD	Computational Aided Design
CAE	Computer-Aided Engineering
C:uh	Ethane
CH4	Methane
CFD	Computational Fluid Dynamics
CO	Carbon Monoxide
C02	Carbon Dioxide
Ce02	Ceria
CuMn	Manganese Coated Copper
CI	Compression Ignition

EDX	Energy Dispersive Analysis
EGR	Exhaust Gas Recirculation
FEIvf	Finite Element Method
FTP	Federal Test Procedures
GDI	Gasoline Direct Injection
GM	General Motors
H2	Hydrogen
H20	Water
HC	Hydrocarbon
HCL	Hydrochloric Acid
HCHO	Formaldehyde
ICE	Internal Combustion Engine
IMEP	Indicated Mean Effective Pressure
ISFC	Indicated Specific Fuel Consumption
LDV	Light Duty Vehicle
N2	Nitrogen
NHTSA	National Highway Traffic Safety Administration
NO	Nitric Oxide
NOx	Nitrogen Oxides
02	Oxygen
PGM	Platinum Group Metal
PM	Particulate Matter
Pt	Platinum
Pd	Palladium
Rh	Rhodium
RPM	Revolution Per Minute
RMSE	Root Mean Square Error
SEJvf	Scanning Electron Microscopy
SFC	Specific Fuel Consumption
Sf	Spark Ignition
Si02	Silica Quartz
so2	Sulphur Dioxide
TDC	Top Dead Centre

TiO	Titanium Oxide
TWC	Three Way Catalytic
US	United States
WSSWM	Woven Stainless Steel Wire Mesh
Zr02	Zirconia

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CHAPTER1

INTRODUCTION

1.1 Background of Study

One of the major sources for air pollution is from the road transport (Mallissery et al., 2017; Banjare et al., 2012). The transportations emission contributes to 13.5% global warming and this sector has the fastest carbon emissions growing comparing to other economic sector. Pollutant emits by the passenger cars have been in force but the desire improvements regarding the air quality have not been materialized yet (European Economic Area, 2014). According to World Health Organization (2014), air pollution bring effects to the health which is known as the fourth largest risk after blood pressure, dietary problems and smoking. Automotive engines are one of the major sources of pollutant, which is harmful to living creatures and causes damage to the environment (Hesterberg et al., 2012). Numbers of road vehicles keeps increasing especially in the populated regions and it have a tendency to increase the percentage of emissions in urban areas. This will lead to increase the exposure of vehicles emission pollutants to the individuals comparing to other sources of exposure. The emission from the automobiles engines brings uncomfortable condition to the environment through the combustion from the engine that produces several harmful gases such as Nitrogen Oxide (NO_x), Carbon Monoxide (CO), unburned of Hydrocarbons (HC). The emissions from the vehicles are depends on the fuels and engines types. Other than that, the technology used for after treatment process also affect the percentage of emissions (World Energy Outlook, 2014).

Number of gasoline-driven vehicles keep increasing from a few thousand to several hundred million in this 21th centuries. These promote more exhaust emissions from combustion of gasoline consequently affected by fuel grade, vehicle age, vehicle model, engine size, fuel type and delivery system, catalytic converter, vehicle maintenance and road network and country of origin (tv.[ohamed, 2015). According to Boulter eta!., (2012), the emission trend is expected to keep increasing for next three decades that con-esponding with the pollutions growth in the atrnosphet-e. The pollutant gases from the vehicles engine not only affect human health but also brings affect to the environment through many unpleasant ways. This is the reasons that the emission limits are being introduced around the world and it becomes stricter as year changes. Table 1.1 shows the emission standard in ASEAN countries of Light Duty Vehicle (LDV) (Silitonga et a!., 2012). It can be seen that most of the ASEAN countries has recently implement Euro 4 specifications on light duty vehicle emission standard.

Table 1.1: Comparison of Light Duty Vehicle (LDV) Emissions Standard in ASEAN countries (Silitonga eta!., 2012)

	Year (2000)		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
Brunei	Diesel															Euro 1				Euro 4	
	Petrol															Euro 2				Euro 4	
Indonesia												Euro 2								Euro 4	
Malaysia							Euro 1								Euro 2					Euro 4	
Philippines							Euro 1						Euro 2							Euro 4	
Singapore	Diesel			Euro 2								Euro 4					Euro 5				Euro 6
	Petrol								Euro 2								Euro 4				Euro 6
Thailand				Euro2							Euro 3								Euro 4		
Vietnam														Euro 2							Euro 4

The challenging issues faced by the automotive engineering sectors are throughout the growth of advanced technologies for the intentions in lowering the impact towards environment where mostly tesearchers competing in cont.tibute new ideas to further decrease the automobiles exhaust emissions. In early 1909, researchers have concern about the important of engine emissions control in order to follow the standards of automobiles emissions that introduced by the United States government. Due to the regulation, alternative emission filtering devices has been introduced which is known as catalytic convetter. This device acts as a pollutant gases conversion that can be attached at the vehicles exhaust pipeline (Mohiuddin and Nurhafez, 2007). In the automobiles industries, development of catalytic converters is one of the major success as this device is able reduce the levels of unwanted emission components to low concentrations level. Catalytic converters have several types of design concepts, filter structures and materials used for the filter development which depends on the vehicles desires. According to Budisa and Makuch (2013), the main pollutant emissions produces from the engine fuel combustion is Carbon Dioxide (C02) and other types of greenhouse gases which also needs to be reduced. These gases affect the local health and environment condition especially in increasing the global warming and chemistry lies in the atmospheric (Shearer et al., 2014). Catalytic converter becomes an important device for the after treatment process for exhaust emissions reduction and classified as three-ways and two-ways catalytic converter. Mansha et al., (2013) and Auckenthaler (2005) stated that two-way catalytic converter only reacts on two gases which are CO and unburned HC while three-way catalytic converter (TWCs) works on NOx, CO and unburned HC.

Three-way catalytic converter (TWCs) controls the air to fuel ratio (AFR) of the vehicles engines through the operation in the close loop system. The activation catalyst in the monolith substrate is capable in controlling the emissions in three ways by concurrently oxidize the CO and HC gases to C02 and water (H20) while NOx gases to nitrogen (N). Two common substrates which are ceramic and metallic are being used by the catalyst to merge with the active coating combines with alumina and other types of precious noble metals such as Rhodium (Rh), Palladium (Pd) and also Platinum (Pt) which is suitable in improving the oxidation process occurs in the monolith substrates. Through the manufacturing of packed back converters, it is realized that the monolith substrates may results in lowering back pressure compare to the packed bed converters which gives effect to the performance of engine especially the engine power performance by producing high flow rate. The wall channel of monolith substrate is mostly coated with porous material normally known as washcoat and fine dispersed noble metal particles. The washcoat will allows conversion to be occurs (Mansha, 2013).

Performance of catalytic converter has been explored for the last several decades. It involves several parameters including design and performance of the catalytic converter in order to meet the government emission regulations. Through the development of the advanced computational and software devices, the emission study areas remain more attractive and precise. One of the objective in this study is to simulate the flow contribution. In order to achieve the objective, ANSYS simulation software was used as the computational tool to investigate the models of catalytic converter. The computational model is required by the design engineer that to simulate the gases conversions, catalyst types and catalyst geometries. This would then provide the designer with strong indications of the performance of the system at an early stage.

1.2 Problem Statement

Automotive Three-Way Catalysts (TWC) were introduced more than 40 years ago. Despite that, the development of a sustainable TWC still remains a critical research topic owing to the increasingly stringent emission regulations. The performance of catalytic converter depends on several parameters that will influenced the performance in converting the toxic gases (Yap et al., 2011). Improving the performance of catalytic converters requires intensive experimental investigations to study the flow behaviour inside the catalytic converter. Understanding the fluid flow behaviour inside the catalytic converter will allow to highlight what is needed to be improved. This requires very accurate fluid flow and pollutant concentration measurement instruments (Hesham et al., 2017). There have been a vastly increased interest in experimental and numerical studies that investigated the performance of the catalytic converters. Several published research results has shown that performance of a typical catalytic converter design by looking at temperature, velocity and static pressure distribution across the converter (Hesham et al., 2017; Sathapom, 2016; Marghmaleki, 2010). Porter (2016) has experimentally investigated the various porous medium modelling approaches and transient flow through a simplified catalyst system geometry in order to develop novel methodologies for modelling catalyst monoliths for the improvement of CFD predictions.

Silva et al. (2006) evaluated the conversion efficiency of a catalytic converter under steady operating condition. The inlet and outlet chemical species concentration, temperature and air fuel ratio (A/F) were measured as a function of the brake mean effective pressure (BMEP) and engine speed (rpm). Pannone and Mueller (2001) and Santos and Costa (2008) have compared catalyst system using ceramic and metallic substrates in order to assess the influence of various substrate parameters on the exhaust gas conversion efficiencies. Therefore, it is intended to use numerical simulations along with experimental validation to investigate and improve the thermal performance of catalytic converters by being able to optimize the converter design. The results were then being validated with the experimental data to compare the percentage ofthe absolute error (Hayes et al., 2012). Some validation ofthe models of catalytic converter has been undertaken but as yet such studies were limited on the exhaust gas conversion data for different catalyst types. Modelling for 3D catalyst needs an accurate meshing with good geometry. This thesis addresses these issues through the development and analysis of catalytic converter model. This study attempts to analyze the performance ofthe ceramic and metallic catalytic converter on its conversion efficiency through experimental and simulation process. The comparison as made between honeycomb structure from ceramic materials catalytic converter and corrugated structure to measure the flow distribution in the selected conditions.

1.3 Research Objectives

The objectives ofthis study are:

1. To examine the pollutant gases conversion of substrate materials in reducing CO, HC and NOx of gasoline engine through experimental measurement.
n. To investigate the internal combustion engine performance and emission characteristics of ceramic and metallic catalytic converter.
m. To evaluate the internal flow pattern of ceramic and metallic catalytic converter in terms of velocity, temperature and pressure distribution.

1.4 Research Scopes

The scopes ofthis study are as follows:

1. Two types of catalytic converters were used which are standard ceramic and standard metallic catalytic converter.
n. Mitsubishi 4G93 used as test engine.
m. The engine speeds used in this study were 1000 rpm, 2000 rpm, 3000 rpm and 4000 rpm respectively.
1v. Analyzing the internal flow in catalytic converter through simulation process using ANSYS Software.

1.5 Significant of Study

Pollution from gasoline-powered vehicles is a major contributor to urban air quality problems throughout the world. Internal combustion engine (ICE) are mostly used by the conventional vehicles where the combustion reaction between fuels and oxygen will produces heat and other types of pollutant gases (CO, HC and NOx) (Zoroofi, 2008). HC fuel reacts in the combustion engine and produces several types of gases other than CO_2 and H_2O while these three gases NOx, CO, HC are toxic to human health.

The vehicles, if left uncontrolled, emit high quantities of HC and NOx that contribute to urban smog, as well as CO which causes respiratory and heart problems (Mansha et al., 2013). The catalytic converter device was mostly has been installed by the manufacturers to the vehicles including light duty trucks in order to meets vehicles emission standard. It is to ensure that the gas emission from vehicle exhaust was safe to be exposed into the atmosphere (Balenovic, 2002). Thus, this will reduce the emission concentration in the atmosphere that created by automotive emissions and at the same times it will also reduce the percentage of human health effect from the pollutant emissions resulting the incidence of cancer and lung disease. From the reduction of pollutant gases from the vehicles emission, the accumulation of the greenhouse gases lies in the atmosphere will brings positive impact towards the rate ofthe global warming.

1.7 Thesis Outline

Chapter 1: This chapter consists ofthe background ofthe study, general introduction of the problem, research objectives, scope of study and the significant research outcome.

Chapter 2: This chapter presents the topic related to the catalytic converter design and concepts highlights the emission problem. This leads on to a review of operational use of catalytic converter and its structure. Accordingly, the review also includes previous work on engine simulation in order to understand the strengths and limitations of the tools.

Chapter 3: This chapter described the methodology and engine facilities used for experimental measurement of performance and exhaust emission ofthe engine. In this chapter the geometry, meshing, boundary conditions use for the simulation process and the engine operational setup is described.

Chapter 4: This chapter consists of simulation results by comparing two types of substrate geometry. The result from the experimental measurement of engine performance and exhaust emission of different type of after-treatment systems. The discussion of the results that are obtained from simulation of the geometry model are presented and the emission of testing is analysed and discussed.

Chapter 5: It consists of conclusion of the result obtains from the analysis and areas requiring further work to improve the experimental work and engine model are being discussed.

CHAPTER2

LITERATURE REVIEW

2.1 Introduction

This chapter present overview of combustion in Internal Combustion Engine (ICE) which produces several types of harmful pollutant gases and composition of the gases in cold start and warm-up condition. The regulation of vehicle emission standard and previous research related to the component of catalytic converter in exhaust system application also being highlight in this chapter. It discusses on the development of ceramics and metallic substrate and its properties in which affect the overall performance of the catalytic converter in reducing the vehicle exhaust emissions. The explanation of modelling in catalytic converter using ANSYS Software is also being presented.

2.2 Emission of Internal Combustion Engine

Internal combustion engines (ICE) are still the most common and reliable power source for power-propelled vehicles and most are reciprocating engines. This type of engine have pistons within the engine that reciprocate back and forth in order to work. The purpose of using combustion engines is converting chemical (fuel) reactions to the mechanical work through a suitable mechanism. These engines have been classified based on different criteria such as the type of fuel, working cycle, and ignition methods (Vishkarma and Kumar, 2016) and can be arranged in variety geometric configurations.

ICE engines can also be categorized based on the fuel ignition such as:

(i) Spark ignition engine (SI): the fuel is ignited via a spark plug, which is placed at the top ofthe cylinder.
(ii) Compression ignition engine (CI): the fuel, diesel, in this type has lower self-ignition temperature compared to SI engines. Therefore, by increasing the cylinder pressure the temperature inside the cylinder is also increased.

The ICE have been widely used in commercial vehicle powertrains which usually working for four stroke engines. The schematic of a four stroke cycle is shown in Figure 2.1. The process is started by supplying fresh air and fuel into the engine cylinder. This usually be conducted by the intake valve to obtain the air-fuel mixture before being compressed up to a certain level, close to the top dead centre (1DC), where the fuel mixture is ignited via the spark plug (Prasanth et al., 2012).

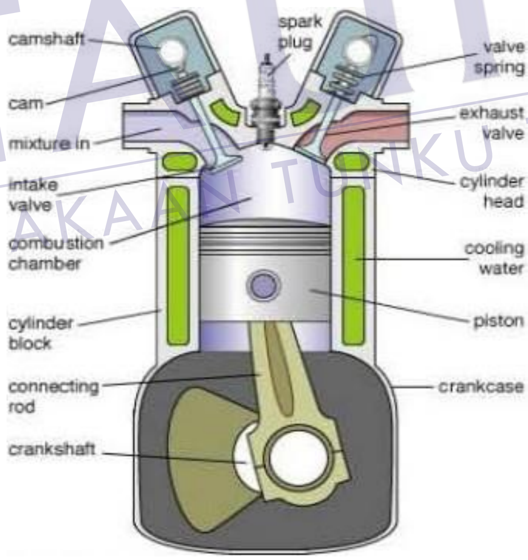

Figure 2.1: ICE Engine cut view (Silva. 2006)

Recent technology and development in automotive industty were intent to focus on the reductions in exhaust emissions however the increasing population in the registered automobiles in each year has causing the emission problem will still to be occur for many years to come. Emission problem has causing a vast increase health and pollution problems caused by the incomplete combustion of exhaust components.

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