APPROVAL

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of degree of Bachelor Mechanical Engineering (Thermal-Fluids)"

Signature	:	…………………………
Supervisor's Name	:	…………………………
Date	:	…………………………

THE STUDY OF FLOW VISUALIZATION ON LNT CATALYTIC CONVERTER USING CFD-FLUENT

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This report is submitted as partial requirement for the completion of the award of Bachelor of Mechanical Engineering (Thermal Fluids) Degree Programme

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DECLARATION

"I hereby, declare this thesis is result of my own research except as cited in the references"

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ABSTRAK

Perlepasan asap daripada engin kereta merupakan salah satu sumber pencemaran udara yang amat membimbangkan. Sifat engin diesel yang menjimatkan penggunaan minyak telah mendapat sambutan yang hangat di kalangan pengeluar kenderaan. Dengan ini, telah dijangkakan kuantiti kenderaan diesel akan berganda dalam jangka masa yang akan datang. Namun demikian, kelemahan utama engin diesel ialah pembebasan kandungan ‘Nitrogen Oxide’(NOx) dan zarahan ‘Particulate Matter’(PM) yang tinggi dalam kandungan asapnya. Kaedah mangkin ‘Lean NOx Trap’ (LNT) telah diterap ke dalam bidang ini dengan jaminan untuk menangani masalah ini dengan berkesan. Kajian ini memberi tumpuan kepada pengaliran asap dalam LNT dengan mengunakan kaedah perisian pembantuan computer CFD-FLUENT. Perisian komputer ini membolehkan pembaca seolah-olah Nampak cara pengaliran asap yang bermula daripada peresap, yang kemudiannya melalui stuktur monolit dan akhirnya terlepas melalui muncung. Kajian ini juga membuktikan bahawa kadar kelajuan pengaliran asap adalah bergantung kepada luas keratan rentas penukar bermangkin. Kaedah bahantara berliang juga digunakan untuk mensimulasikan material monolit dalam perisian komputer.

ABSTRACT

Emission from prime mover had caused inevitable pollutions to the environment. Diesel engine has gained the hearts of many car manufacturers due to its fuel economic characteristic. As the result, the quantity of diesel powered vehicle, are predicted to double in the coming future. However, diesel engine faces a major drawback as it produces huge amount of soot and NOx emission. The LNT converter which promises to provide the most effective NOx reduction in diesel engine, were being studied in this research in terms of the fluid flow across the catalytic converter. Flow visualization simulated by using the CFD FLUENT offers the audience to be able to actually see the pattern of the flow as it crosses from the inlet diffuser and exits through the outlet nozzle of the LNT catalytic converter. The velocity of the flow was proven to be dependent on the cross sectional area of the catalytic converter. The porous medium approach was applied to the monolithic structure in order to simulate the flow as predicted in an actual case, whereby only laminar flow existed along the monolith structure.

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NOMENCLATURE

Al_2O_3	Alumina
BaO	Barium Oxide
CaO	Calcium Oxide
CARB	California Air Resource Board
CO	Corbon Monoxide
CO_2	Corbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EPA	Environment Protection Agency
EURO / EU	European Union
HC	Hydrocarbon
IC	Internal Combustion
LNT	Lean NOx Trap
N_2	Nitrogen gas
N_2O	Dinitrogen Monoxide
N_2O_3	Dinitrogen Trioxide
N_2O_4	Dinitrogen Trioxide
N_2O_5	Dinitrogen Pentroxide
Na_2O	Sodium Oxide
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxide
NSR	NOx Storage Reduction Catalyst
PM	Particulate Matter
CFD	Computational Fluid Dynamic
SCR	Selective Catalytic Reduction

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The need for more energy in developing countries has substantially contributes to severe environmental pollutions. Increasing demands for long range transportation are one of the responsible facts that contribute to such problem. Vehicles with either gasoline engine or diesel engine, burn fuel to generate power, which eventually release harmful substances such as Carbon Monoxide (CO); Hydrocarbons (HC); Particulate Matter (PM) or soot; and Nitrogen Oxides (NOx). These substances do not only pollute the air, but they are also one of the main factors in causing adverse human health.

In 1892, Sir Rudolph Diesel had created the most efficient prime mover ever since—the diesel powered engine. The urge of achieving better fuel efficiency and lower Carbon Dioxide emission, these engines are designed to run closer to the lean-burned condition. However, the excess amount of Oxygen in the exhaust stream has made difficult for NOx reduction. By judging the re-senses of environmental quality and human health policy, world wide emission control bodies, such as the European Union (EU); the United States Environmental Protection Agency (EPA); and the California Air Resources Board (CARB), had taken drastic steps in tightening the NOx emission legislation.

When the available three-way-catalyst (TWC) was proven to be ineffective for NOx removal, new approaches for NOx reduction in lean-burned diesel engine are considered. By early 2006, the lean NOx trap (LNT) catalyst seems to be the most promising NOx reduction technology under consideration. Discovered by Toyota in the mid 90s', the lean NOx trap catalyst consists of earth alkaline oxides on wide surface area base material, which has the ability to store NOx under lean condition and release it as harmless substances during rich engine condition. At January 8th, 2007, the Volkswagen Media Services has made a prediction of releasing the LNT catalyst on its VW Jetta Clean TDi and VW Tiguan concept vehicles. The models are planned to be released into the America market as part of the "BlueTec" program from Audi, Daimler-Chrysler and Volkswagen.

Apart from the effectiveness of the LNT catalyst in reducing harmful substances from the exhaust emission, the flow distribution within the catalytic converter plays an equally important role in determining both the performance of the catalytic converter, as well as the engine performance. The effects of the flow pattern through the 3 main parts of the catalytic converter-the inlet diffuser, the monolithic structure and the outlet nozzle, strictly determine the performance of the exhaust system. The illustration of the flow distribution through the catalytic converter is performed in this study to aid the understanding of the LNT catalytic converter design against the exhaust flow regarding the flow velocity, temperature, pressure, and flow rate. CFD-FLUENT software is used in this study to perform the flow distribution analysis.

1.2 Problem Statement

The combination of diesel engine's refinement, drivability, and fuel economy has entitled it the preference engine in Europe. Ironically, diesel engine produces more NOx than gasoline engine. As focuses were on the effectiveness of the LNT in NOx removal, another arise issue that rarely appeal to the public is the flow pattern within the catalytic converter. Abide from the LNT performance base on its chemical reactions against the exhaust emission; studies were performed to analyze the flow pattern through the diffuser, monolithic structure and the nozzle of the catalytic converter. In completing this study, it is expected to obtain answers for the following open ended questions;

- What is the corresponding flow pattern at the specified parts of the LNT catalytic converter?
- What relation can be built up between the flow distributions within the catalytic converter, against the exhaust emission parameters?

1.3 Project Objectives

The main purpose of this project is to study the flow pattern through the 3 regions of the LNT catalytic converter-the inlet diffuser, the monolithic structure and the outlet nozzle. By fundamentally understanding the operation principle as well as the modeling of the LNT catalyst technology, the main purpose of this project can be achieved with the existence of the listed objectives as the follow;

1- To understand the working principles of LNT catalyst in diesel exhaust system.
2- To establish a CFD model of LNT catalyst using CFD tools.
3- To perform CFD flow analysis of the LNT catalyst based on different exhaust emission parameters published in established journals or literature.

1.4 Project Scope

This study focuses on the flow distribution that occurs within the LNT catalyst. With the aiding of the CFD-FLUENT software, it is expected to produce a comprehensive illustration of the flow pattern through the 3 main parts of the catalytic converter in terms of flow velocity, temperature, pressure and the flow rate. The summary of the project scope is listed as the follow;

1- Develop a LNT CFD model using CFD tools-CFD-GAMBIT and CFD-FLUENT.
2- Perform CFD analysis on flow distribution through the 3 regions of the LNT catalyst-the inlet diffuser, the monolithic structure and the outlet nozzle.
3- Validate the final result against previous works from reliable journals.

1.5 Project Outline

This report on “The study of CFD flow visualization on LNT catalyst using CFD-FLUENT” is divided into 5 main chapters. Chapter 1 introduces the audience to the general background of this research, the problem statement, project objectives, as well as the project scope. This chapter also offers an overall view of the project outline.

Chapter 2 is a compilation of related information and literature reviews gathered from both published papers and electronic media. Previous works done on automotive catalytic converter flow visualization are also presented in this chapter.

Chapter 3 explains about the experimental methodology used in the study of flow visualization on the LNT catalyst. The experimental methodology consists of 2 main stages-to construct a LNT CFD model; and to test the model under different exhaust emission parameters. The software used in this study is introduced in this chapter as well.

Results obtained from the simulation are presented and discussed thoroughly in this chapter. Chapter 4 displays the outcome results for each simulation based on different exhaust emission parameters. Result data are analyzed and comparisons are made. The result reliability of the study is also discussed and verified in this chapter.

The last chapter in this report—Chapter 5, presents the conclusion and recommendations of this study. Suggestions for future improvements in this study are also stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental of Internal Combustion Engine

The Internal Combustion engine or better known as the IC engine, is defined as a power source whereby fuel combustion takes place in a confined space, which produces gas expansion that are used directly to provide mechanical power. Generally, the IC engine is classified into 2 main categories—the spark-ignition engine and the compression-ignition engine. These engines are of reciprocating or piston engine that runs either with a 4-strokes or 2-strokes cycle.

The spark-ignition engine generates power through combustion process triggered by igniting the fuel-air mixture with a spark produced from a spark-plug. The spark-ignition engine is also commonly known as the "gasoline engine" in America and as "petrol engine" in Britain. The compression-ignition engine, also known as the diesel engine, generates power with an auto ignites combustion process, whereby the fuel auto-ignites without the help of an external source such as a spark plug. A spark-ignition engine has a compression ratio between 9:1 and 10:1, whereby a diesel engine has a much higher compression ratio-25:1. The high compression ratio in a diesel engine is needed for air to be compressed at high temperature, which is around 700 – 900˚C. Under this condition, the fuel ignites automatically as it came in contact with the air. Pre-mixing of fuel and air allows the spark-ignition engine to run at a much higher speed than a diesel, but it severely limits their compression, and thus lowering their fuel efficiency.

2.2 Exhaust System

In automotive terms, the exhaust system refers to a series of piping system that guide waste exhaust gases away from a controlled combustion inside an engine. The basic concept of the exhaust system is to carry noxious and toxic gases away from the users of the machine, by conveying the hot burnt gases from the engine through a numbers of vital components, such as the exhaust manifold, catalytic converters, muffler, and finally dispersing it through the tailpipe tip at the end of the whole piping system. The by-products of combustion from the engine were then vented into the atmosphere.

One of the principles in exhaust system manufacturing states that the exhaust pipe must be heat-resistant, and it must not pass through or be near anything which can burn or can be damaged by heat. The following figure shows the installation and the location of a typical exhaust system on a commercial vehicle.

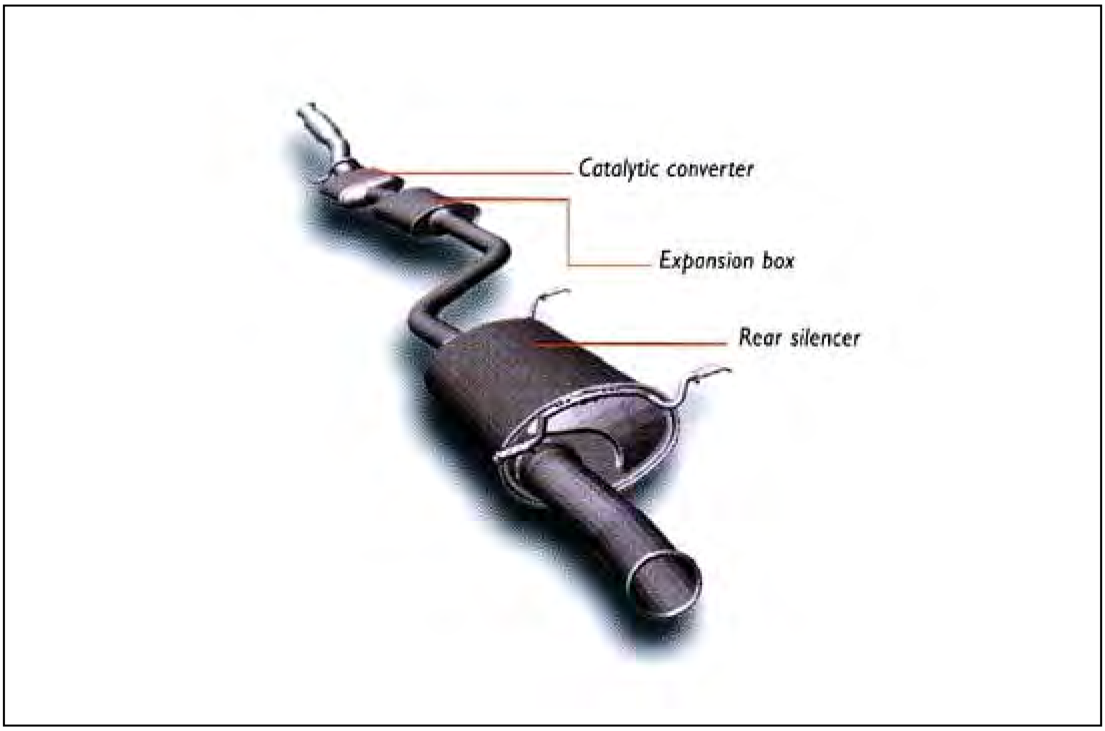

Figure 1: The typical exhaust system on a commercial car
(Source: http://www.activeserviceltd.co.uk/exhausts.htm)

The functions for the main parts of the exhaust system is summarized and presented in the following table.

Table 1: The breakdown of the Automotive Exhaust System
(Source: Author)

Part	Description
Exhaust Manifold 	■ Other names: extractor, exhaust head or header. ■ Material: cast iron, mild steel or stainless steel. ■ It is an assembly designed to collect the exhaust gas from two or more cylinders into one pipe. ■ It is designed as a few circular steel tubing that bends and folds, creating a path from each cylinder's exhaust port to the common outlet at equal length. ■ The paths are connected to the outlet pipe at narrow angles that creates pressure waves that flow through the outlet, preventing the exhaust gas to revert back to the cylinder or in the direction of the other cylinders.
Catalytic Converter 	■ It is a filter like device that chemically filters or converts the harmful exhaust gases components into less harmful gases. ■ Example: DOC, TWC, DPF, SCR and the LNT.

Muffler 	■ Other names: silencer. ■ Function: Noise reduction emitted by the engine. ■ It is designed to have a resonating chamber, which is specifically tuned to cause destructive interference, whereby the opposite sound waves hits and cancel out each other, resulting in the final noise reduction. ■ Example noise frequency absorption material: Fiberglass.
Tailpipe and Tip 	■ It is located at the end of the final length of exhaust pipe where it vents to the open air. ■ It is the most visible part of the entire exhaust system. ■ It is the final pressure reduction part of the entire exhaust system.

The common problem faced by exhaust system design is the back pressure occurrence. Back pressure in an exhaust system, which is caused by the back flow of the exhaust gas back to the cylinders, is considered as a restriction that can restrict the engine's true performance possibilities. For example, back pressure can cause suffocating of the engine and robbing the horsepower and gas mileage of the vehicle. Back pressure can also cause further damages to the engine as well as the system. The carefully fabricated or engineered connections of the exhaust piping system are also capable of enhancing the exhaust flow regarding a particular engine RPM range, which provide the user with the up-most satisfactory enjoying the maximum horsepower produced by the engine.

2.3 Exhaust Emission Compositions

The exhaust emission substances produced by both spark-ignition engine and diesel engine are similarly the same-HC, CO, NOx and PM. The exhaust emission from a spark-ignition engine has a much lower amount of NOx and PM if compared to the exhaust compounds of a diesel engine. However, in fuel economic wise, the diesel engine had proven to be the better choice. But due to the combustion process sets to occur towards the lean side, and also because of the present of Sulfur based compound in the fuel, the diesel engine tends to generate relatively large amount of NOx and PM emission, which requires various hard works to be done in order to fully utilize the diesel engine without reducing it's engine performance. The following table presents the exhaust composition and exhaust gas temperature based on a few types on engines.

Table 2: Exhaust composition and exhaust gas temperature of different engine type (Source: G. C. Koltsakis, 1997)

	CO (%)	Temperature (°C)	HC (ppmC)	NO_x (ppm)	Particulate (g/kWh)	O_2 (%)
Diesel	0.01-0.2	80-700	100-2000	200-1000	0.15-0.5	3-15
Otto lean-burn	0.05-0.5	100-900	1000-5000	100-1000	—	0.5-5
Otto	0.3-1	150-1000	1000-5000	50-2500	—	0.1-0.5
Otto CNG fuelled	0.1-0.5	100-900	1000-3000	50-2000	—	0.1-0.5

2.3.1 NOx Formation in Diesel Engine

According to Bertrand D. Hsu, during the presents of Oxygen, over 90% of the formed NOx compound appears in the form of NO (Nitric Oxide) and NO_2 (Nitrogen Dioxide). Other compounds such as N_2O (Dinitrogen Monoxide), N_2O_3 (Dinitrogen Trioxide), N_2O_4 (Dinitrogen Trioxide) and N_2O_5 (Dinitrogen Pentroxide), appeared in negligible amount. These compounds are generally knows as Nitrogen Oxides or NOx. At high temperature, NO appears to be in a stable form, but as the temperature is reduced to room temperature, NO will subsequently be oxidized into NO_2.