

DEVELOPMENT OF A COMPRESSED NATURAL GAS (CNG) MIXER FOR A
TWO STROKE INTERNAL COMBUSTION ENGINE

DEVARAJAN A/L RAMASAMY

UNIVERSITI TEKNOLOGI MALAYSIA

DEVELOPMENT OF A COMPRESSED NATURAL GAS (CNG) MIXER FOR A
TWO STROKE INTERNAL COMBUSTION ENGINE

DEVARAJAN A/L RAMASAMY

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Masters of Engineering (Mechanical)

Fakulti Kejuruteraan Mekanikal
Universiti Teknologi Malaysia

OCTOBER 2005

ABSTRACT

Compressed Natural Gas (CNG) has been accepted widely as an alternative to gasoline. More importantly the use of CNG in two stroke engines will drastically reduce the high emission output from these engines as these engines are widely used around the world. A conversion kit is used to apply the fuel in engines. A bifuel conversion system converts engines without much modification to other systems. They are normally produced for four stroke application. This kit has to be studied to be modified for two stroke application. The part that connects the engine to the kit is called a gaseous fuel mixer. This part mixes the air and fuel due to its venturi shape. A mixer provides fuel suction at different engine speeds due to pressure difference at the throat. The optimisation of the throat is important as a small throat will cause poor performance at high speeds while a large throat will reduce fuel suction. The smaller throat size creates higher velocity and lower pressure. This low pressure creates fuel suction into the mixer. The mixer was designed for a two stroke engine air flow. Computer aided design (CAD) and computational fluid dynamic (CFD) software were used as a tool for the design. The design is optimised for inlet and outlet angles, number and size of the hole at the throat circumference and also the throat size. The prototype design was manufactured based on optimised dimensions of the mixer that were obtained from CFD analysis. The mixer was validated to show that the CFD analysis was correct. Testing apparatus were used to do the validation. The apparatus consists of a laminar flow element (LFE), a smoke generator, a digital manometer and a gaseous flow meter. It was used to validate the flow pattern, pressure drop from the mixer and the air fuel ratio given by the mixer.

ABSTRAK

Gas Asli Termampat (CNG) telah diperakui sebagai satu alternatif kepada petrol. Penggunaan gas ini dalam enjin dua lejang mampu mengurangkan pengeluaran pencemaran tinggi dari enjin ini. Ini kerana penggunaan enjin dua lejang adalah banyak di dunia. Bahan api ini digunakan pada engine melalui kit penukaran. Penukaran enjin petrol ke CNG perlu dilakukan dengan modifikasi kecil pada enjin asal. Oleh itu, kit penukar CNG dwibahanapi digunakan. Unit ini dibuat lazimnya untuk enjin empat lejang, oleh itu, ia perlu dikaji bagi penggunaan dalam enjin dua lejang. Bahagian pada alat ini yang bersambung kepada enjin dinamakan sebagai pencampur bahanapi bergas. Ia menyebabkan gas bercampur pada bahagian yang berbentuk venturi. Pencampur ini memberikan sedutan gas kepada enjin pada halaju enjin yang berbeza disebabkan perbezaan tekanan pada bahagian yang dipanggil leher. Ubahsuai leher adalah penting bagi operasi alat ini. Ubahsuai leher adalah perlu kerana leher yang kecil akan menyebabkan prestasi enjin yang rendah pada kelajuan tinggi manakala leher yang besar tidak dapat memberi sedutan gas yang diperlukan. Tekanan rendah menyebabkan sedutan pada pencampur ini. Pencampur direkabentuk untuk aliran udara pada enjin dua lejang. Rekabentuk berbantuan computer (CAD) dan Dinamik Bendalir berbantuan computer (CFD) digunakan sebagai alat rekabentuk. Rekabentuk pencampur diubahsuai dengan menggunakan CFD pada sudut masukan dan keluaran, bilangan lubang dan saiz lubang pada leher serta saiz leher itu sendiri. Prototaip dibuat berdasarkan dimensi pencampur yang diperolehi daripada analisis CFD. Untuk membuktikan analisis CFD pengesahan telah dilakukan. Peralatan ujikaji telah digunakan untuk melakukan pengesahan ini. Ia terdiri daripada elemen aliran laminar (LFE) penghasil asap, manometer digital dan meter aliran gas. Peralatan ini digunakan bagi tujuan pengesahan bentuk aliran, kejatuhan tekanan dan nisbah udara kepada bahan api yang diberi oleh pencampur ini.

CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF APPENDICES	xiv
	LIST OF SYMBOLS	xv
1	INTRODUCTION	1
	1.1 Problem Statement	2
	1.2 Objectives	3
	1.3 Scope	3
	1.4 Methodology	3

2	LITERATURE REVIEW	5
2.1	Two Stroke Engine	5
2.2	CNG as Fuel for Two Stroke Engines	6
2.2.1	CNG as an Alternative Fuel	7
2.2.2	Combustion Characteristics of CNG	10
2.2.3	Emission Reduction from CNG Usage in Two Stroke Engines	11
2.2.4	Other Issues Regarding CNG Usage	13
2.3	CNG Mixer	14
2.3.1	Current Trends in CNG Mixer Design	15
2.3.2	Sizing of the Mixer Throat	18
2.3.3	Pressure Drop in the Mixer	19
2.3.4	CNG Mixer and Engine Conversion Kits	23
2.4	Summary of Literature Review	24
3	DESIGN OF A VENTURI BURNER MIXER	25
3.1	Conceptual Design	26
3.2	Procedure of Mixer Design	28
3.2.1	Initial Throat Size	29
3.2.2	CFD Simulations of the Mixer	30
3.2.3	Inlet and Outlet Angles of the Mixer	34
3.2.4	Number of Holes at Throat Circumference	36
3.2.5	Size of Hole at Throat Circumference	37
3.2.6	Throat Size Optimisation	37
3.3	Prototyping the Mixer	38
3.4	Validating the Mixer Design	39
3.4.1	Testing Apparatus	39
3.4.2	Testing Procedure	42
3.4.2.1	Smoke Mixing in Mixer	43
3.4.2.2	AF Ratio Test	43

3.4.2.3	Pressure Drop Test	46
4	RESULT AND DISCUSSION	47
4.1	Designing of the Mixer	47
4.1.1	Initial Throat Size	47
4.1.2	CFD Simulation of the Mixer	48
4.1.3	Inlet and Outlet Angles of the Mixer	48
4.1.4	Number of Holes at Throat Circumference	52
4.1.5	Size of Hole at Throat Circumference	56
4.1.6	Throat Size Optimisation	58
4.2	Prototyping the Mixer	63
4.3	Validating the Mixer Design	65
4.3.1	Smoke Mixing in Perspex Prototype	65
4.3.2	AF ratio Testing of Mixer	67
4.3.3	Pressure Drop Testing of Mixer	69
5	CONCLUSION AND RECOMMENDATION	72
5.1	Conclusion	72
5.3	Recommendation	73
	REFERENCES	74
	APPENDICES	77
	Appendix A	77
	Appendix B	79

Appendix C	109
Appendix D	117
Appendix E	125
Appendix F	128

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Energy content of alternative fuels relative to petrol and diesel	8
2.2	Proven natural gas reserves	8
2.3	Average natural gas composition in Malaysia	9
2.4	Methane gas properties	10
2.5	Typical 2stroke emissions	12
2.6	Current regulation that is available for twostroke engines	12
2.7	Fuel price	13
3.1	Specification of the analysed engine	29
3.2	Properties of air	33
5.1	Specification of the mixer designed	73

LIST OF FIGURES

FIGURE NO.	TITLE	PAGES
1.1	Methodology	4
2.1	Operation of a two stroke engine	6
2.2	Type of CNG mixers currently being used in the market	15
2.3	Power test results for different mixer designs	16
2.4	Venturi upstream of the carburettor	18
2.5	Mixer after throttle in intake system of injection engine.	18
2.6	Schematic plot of velocity and pressure across a venturi	20
2.7	Pressure profile during intake stroke of an engine	21
2.8	Pressure drop in air cleaner and intake manifold	22
3.1	Methodology for designing the CNG mixer	25
3.2	The concept models	27
3.3	Proposed shape of the mixer	28
3.4	Location of throat diameter	30
3.5	Simulation steps for each simulation	32
3.6	Overall simulation stages done on the mixer	34
3.7	Simulation model for inlet and outlet angles	35
3.8	Schematic diagram of flow test rig to measure air flow	40
3.9	Schematic of smoke generator connected to test rig	41
3.10	Schematic diagram of pressure measurement	42
4.1	Pressure plot along the centre line of the mixer at different inlet and outlet angles	49
4.2	Lowest pressure at the throat diffuser wall	50
4.3	Pressure ratios of each model inlet and outlet angle changes	51
4.4	Eight holes mixer model	53
4.5	Ten holes mixer model	54

4.6	Twelve holes mixer model	55
4.7	Effect of AF ratio on hole sizes at throat circumference at all speed range	57
4.8	Effect of throat diameter size on air fuel ratio	60
4.9	Simulation pressure drop due to different throat size at all engine speed	62
4.10	Perspex model for flow testing	63
4.11	Assembled view of Aluminium mixer	64
4.12	Components of Aluminium mixer	64
4.13	Simulation of smoke at 1000 rpm, 2000 rpm and 3000 rpm air speed	66
4.14	Experiment and simulation results of AF ratio	68
4.15	Simulations and experiment pressure drop	71

LIST OF APPENDICES

APPENDIX	TITLE	PAGES
A	Thesis Gantt Chart	7
B	CFD Analysis	9
C	Apparatus and Experiments	109
D	Technical Drawings	117
E	Material Selection	125
F	Mesh Independant Analysis	128

LIST OF SYMBOLS

AF	Air fuel ratio	-
A_1	Area in inlet	m^2
A_2	Area at throat	m^2
C_μ	Viscosity constant	-
C_v	Specific heat	J/kgK
Dr	Delivery ratio	-
H_L	Losses in pipe	Pa
k	Turbulent kinetic energy	J/kg
\dot{m}_1	Inlet mass flow rate	kg/s
N	Engine speed	rpm
Q_a	Volumetric air flow rate	m^3/s
Q_1	Measured flow rate	m^3/s
Q_2	Actual flow rate	m^3/s
p_{atm}	Atmospheric pressure	Pa
Q_H	Heat source per unit volume	J/m^3
q_i	Diffusive heat flux	J/s
S_i	Mass distributed external force per unit mass	N/kg
U	Fluid velocity	m/s
v_1	Velocity at inlet	m/s
v_2	Velocity at throat	m/s
Δp	Pressure drop	Pa
ΔP_{air}	Pressure drop in the air cleaner	Pa
ΔP_u	Intake pressure drop upstream	Pa
ΔP_{thr}	Pressure drop across throttle	Pa

ΔP_{valve}	Pressure drop across intake valve	Pa
ρ_1	Air density at inlet	kgm^{-3}
f_μ	Turbulent viscosity factor.	-
δ_{ij}	Kronecker delta function	-
ε	Turbulent dissipation	J s^{-1}
θ	Angle	°
τ_{ik}	Viscous shear stress tensor	Pa
μ	Dynamic viscosity	$\text{kgm}^{-1} \text{s}^{-1}$
μ_l	Dynamic viscosity	$\text{kgm}^{-1} \text{s}^{-1}$
μ_t	Turbulent eddy viscosity	$\text{kgm}^{-1} \text{s}^{-1}$

CHAPTER 1

INTRODUCTION

Current trends in the automotive industry are ever changing especially regarding the usage of alternative fuels. The search for the best alternative fuel that produces the least amount of emission has sparked concerns to many researchers. Maxwell (1995) stated that many studies on alternative fuel have been carried out and researchers are looking at natural gas, liquefied petroleum gas (LPG), methanol, ethanol, and hydrogen. All of these fuels have their advantages and disadvantages which are cost, availability, environmental impact, usage in vehicle, safety and the acceptance by consumers.

Current fuel price inflation and also current oil crisis, drastic moves were taken by many countries to reduce petroleum usage and finding other alternatives to its usage. In developing countries, the concern of finding alternative fuels has started and already had become an issue. With gas reserves three times more than petroleum oil, Malaysia is increasingly turning its attention towards natural gas. The national petroleum company of Malaysia, PETRONAS has embarked on the Natural Gas for Vehicles (NGV) program where NGV dispensing facilities are available at some selected PETRONAS service stations, located in high traffic density areas of Kuala Lumpur and Johor Bahru. The government support for the NGV program was seen in 25% reduction on car road tax for using NGV as well as requiring new taxis in the Klang Valley to use CNG by engine conversion systems.

In automotive applications, natural gas can be used in three forms based on how the natural gas is stored. One of the most popular forms of natural gas is the compressed natural gas (CNG), which is natural gas in pressurised form. The other least popular methods of obtaining natural are liquefied natural gas and the absorption natural gas.

CNG is a good alternative to petrol and diesel. Consumers would easily accept this form of alternative as it has low operational cost due to subsidised price and its usage could provide cleaner engine emissions. The main reason behind CNG fuel being cleaner is that natural gas is principally comprise of 90% methane, which is the simplest form of hydrocarbon. Even so, the CNG fuel available today still lack in some qualities compared to petroleum fuel. For example, CNG fuelled engines normally possess lower engine performance compared to petrol.

The main reason is that CNG fuelling systems creates a lot of losses in terms of volumetric efficiency. This happens as CNG must be supplied to the engine through a mixing device before the mixture of CNG and air is drawn into the engine. This causes less fuel in the combustion chamber and reduces volumetric efficiency. Currently petrol fuelled engine are converted into a CNG fuelled engine by means of a fuel mixing device.

1.1 Problem Statement

Currently, there are no specific CNG mixers specifically designed for two stroke engines in the market. All of the conversion kits that are available for four stroke engines only. A proper CNG mixer should be designed for two stroke engine application. A supercharged 150 cc two stroke engine has been chosen for CNG conversion. Direct usage of a conventional four stroke engine CNG mixer for two stroke engines is not possible as they are too large a size for a small two stroke engine air requirements. The design of the mixer has to consider the whole range of engine operating condition in order to provide a complete view of its performance.

The existing four stroke engine CNG mixers are usually not properly refined and optimised to enable good air fuel mixing. In addition, the efficiency of the current mixer design is also an issue as it is designed for simplicity which only offers practicality but lack in efficient air flow performance throughout the engine speed. Therefore, a straight forward conversion is not possible.

1.2 Objectives

The objectives of the study are as follows:

- 1) To design a venturi burner type CNG mixer for a two stroke engine according to the engine's air requirement using CFD.
- 2) To fabricate the optimised prototype of the CNG mixer and test it on a flow bench machine.

1.3 Scope

The scopes of the research are as follows:

- 1) Preliminary design of the CNG mixer.
- 2) Optimising the CNG mixer design using CFD as a design tool .
- 3) Fabrication of the prototype CNG mixer.
- 4) Testing and validation of the CNG mixer design.

1.4 Methodology

A general methodology was followed in the research as indicated in the flow chart as shown in Figure 1.1:

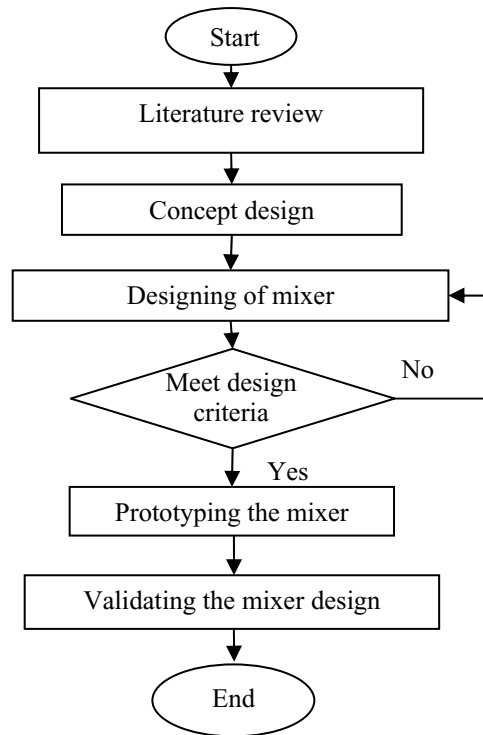


Figure 1.1 Methodology

REFERENCES

- Andreas N. Alexandrou (2001). *Principles of Fluid Mechanics*. Prentice Hall. New Jersey.
- Baert R. S. G., Beckman D. E., Veen A. (1999). *Efficient EGR technology for future HD diesel engine emission targets*. TNO Road Vehicles Research Institute. SAE 1999-01-0837.
- Bryan Willson. (2002). *Direct Injection as a Retrofit Strategy for Reducing Emissions from 2-Stroke Cycle Engines in Asia*. Hong Kong.
- Ferguson, C.R (2001). *Internal Combustion Engines- Applied Thermo-sciences*. John Wiley & Sons. Canada.
- Gan L.M., (2003). *Design and Development of Two Stroke Engine Using Blower Mechanism*. UTM, Thesis.
- Gas Malaysia Sdn. Bhd. (2003). *Natural Gas in Malaysia*. Gas Malaysia
- Heywood J.B (1988). *Internal Combustion Engines Fundamentals*, Mc Graw Hill International Edition. Automotive Technologies Series
- Jitendra (Jitu) Shah, N.Harshadeep (2001), *Urban Pollution from Two Stroke Engine Vehicles in Asia*, Regional Workshop on Reduction of Emissions from 2-3 Wheelers, September 5-7, 2001– Hanoi, Vietnam.
- Landirengo, (2003). *TN-SIC CNG Regulators*. Installation Manual. Landirengo S.p.A. Italy
- Lenz, H.P, (1992). *Mixture Formation in Spark-Ignition Engines*. SAE Inc. New York.
- Luiz Henrique Borges, Carlos Hollnagel and Wilson Muraro. (1996). *Development of Mercedes-Benz Natural Gas Engine M 366 LAG with a Lean Burn System*. SAE Brasil 1996. 962378 E
- Maxwell T.T. and Jones J.C. (1995). *Alternative Fuels: Emissions, Economics and Performance*. USA Society of Automotive Engineers: SAE Inc.

- Mardani Ali Sera, Rosli Abu Bakar, Sin Kwan Leong. (2003). *CNG Engine Performance Improvement Strategy through Advanced Intake System*. Universiti Teknologi Malaysia. JSAE 20030229. SAE 2001-01-1937. Japan.
- Mikio Furuyama, Bo Yan Xu. (1998). *Mixing Flow Phenomena of Natural Gas and Air in the Mixer of a CNG Vehicle*. SAE 981391. Chiba University. Japan.
- Mohamed Maurie Bundu. (1998). *Investigation of the Performance of A Spark Ignition Engine with Gaseous Fuels*. Dalhousie University. Canada
- Poulton M.L. (1994). *Alternative Fuels for Road Vehicles*. Computational Mechanics Publications. Southamton. UK and Boston. USA. Pg 99-121.
- Rosli Abu Bakar, Azhar Abdul Aziz and Mardani Ali Sera. (2002^a). Effect of Air Fuel Mixer Design on Engine Performance and Exhaust Emission Of A CNG Fuelled Vehicles, 2nd World Engineering Congress Sarawak, Malaysia, 22-25 July 2002
- Rosli Abu Bakar, Mardani Ali Sera, Sin Kwan Leong. (2002^b). *Design and Development of New Compressed Natural Gas (CNG) Engine*. IRPA Vol 72351. UTM.
- Rosli Abu Bakar, Devarajan Ramasamy, Gan Leong Ming. (2004). *Design of Compressed Natural Gas (CNG) Mixer Using Computational Fluid Dynamics*. 2nd BSME-ASME International Conference on Thermal Engineering. 2-4 January 2004. Dhaka
- Rosli Abu Bakar, Devarajan Ramasamy, Chiew Chen Wee, (2003). *Effects of Port Sizes in Scavenging Process on New Two-Stroke Engine Using Numerical Analysis*. 3rd International Conference on Numerical Analysis in Engineering, Batam View Beach Resort, 13-15 March.
- Sierra Instruments, (1994). *Top-Trak Mass Flow Meters*. Instruction manual. California. USA.
- Taib Iskandar Mohamad, Mark Jermy, Matthew Harrison, (2003). *Direct Injection of Compressed Natural Gas in Spark Ignition Engines*. ICAST 2003.
- Willard W. Pulkkrabek, (1997). *Engineering Fundamentals of the Internal Combustion Engine*. Prentice Hall.
- Yeap Beng Hi, Azeman Mustafa, Zulkefli Yaacob. (2002). *Computational Investigation of Air-Fuel Mixing System for Natural Gas Powered Motorcycle*. 6th Asia-Pacific International Symposium on Combustion and Energy Utilization 20 – 22 May 2002, Kuala Lumpur

ISBN 983-52-0244-3

Yusoff Ali and Zailani Muhammad (2003). *The Issues Promotion of the Use of Natural Gas in Automotive the New Trend*. ICAST 2003.