



Faculty of Mechanical Engineering

**PRE CHAMBER FOR PERFORMANCE IMPROVEMENT
USING COMPRESSED NATURAL GAS IN SINGLE
CYLINDER ENGINE**

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Master of Science in Mechanical Engineering

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DECLARATION

I declare that this thesis entitled “Pre Chamber For Performance Improvement Using Compressed Natural Gas In Single Cylinder Engine” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature :.....

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Date :.....

DEDICATION

To my beloved father and late mother

ABSTRACT

This thesis is deal with experimental assessment of pre chamber without auxiliary fuel into single cylinder spark ignition engine fuel with compressed natural gas (CNG) fuel. Current problem by CNG fuel in spark ignition engine is lower performance compare to gasoline fuel. Therefore, the objective of this thesis was to investigate and analyse the effect of pre chamber into performance and combustion of single cylinder spark ignition compressed natural gas engine. Methodology of this study was to apply pre chamber into single cylinder engine which use compressed natural gas as fuel source. Engine was tested by using hydraulic dynamometer combine with several sensor equipment. The sensors used during the experiment are high pressure sensor, crank angle encoder, and combustion analyzer (DAQ). The experiment were conducted based on SAE International standard J1349. The result showed that the performance of the single cylinder engine when using CNG was reduced compared to gasoline fuel. However, when pre chamber was applied to an engine, there was some performance improvement only at high engine speed. In terms of combustion, this pre chamber can also reduced in cylinder pressure, rate of heat release (ROHR), and rate of pressure rise (ROPR) compared to gasoline fuel and CNG fuel wihtout using the pre chamber. In conclusion, this study concluded that the pre chamber improve the performance of CNG fuel only at high engine speed (2500 rpm) and reduced the CNG combustion performance at lower engine speed.

ABSTRAK

Tesis ini membentangkan penyelidikan tentang ruang pembakaran awalan tanpa bantuan percikan bahan api untuk enjin palam pencucuh satu silinder dengan gas asli termampat sebagai bahan api. Situasi masalah dari bahan api gas asli termampat adalah penghasilan prestasi enjin palam pencucuh yang rendah berbanding bahan api petrol. Oleh itu, objektif tesis ini adalah untuk mengkaji dan menganalisis kesan penggunaan ruang pembakaran awalan terhadap prestasi dan pembakaran. Metodologi kajian ini adalah mengaplikasi ruang pembakaran awalan terhadap enjin yang menggunakan gas asli termampat sebagai bahan api. Ujikaji terhadap enjin ini dijalankan menggunakan hidraulik dinamometer serta peralatan sensor. Sensor-sensor yang digunakan ketika ujikaji adalah sensor bertekanan tinggi, engkol sudut pengekod, dan analisis pembakaran (DAQ). Ujikaji ini dijalankan berdasarkan piawaian antarabangsa yang ditetapkan oleh SAE antarabangsa J1349. Hasil kajian menunjukkan bahawa prestasi enjin satu silinder ini berkurangan apabila menggunakan gas asli termampat berbanding dengan bahan api petrol. Walau bagaimanapun, apabila ruang pembakaran awalan telah digunakan untuk enjin, terdapat sedikit peningkatan prestasi hanya pada kelajuan enjin tinggi. Dari segi pembakaran, ruang pembakaran awal ini juga mengurangkan tekanan silinder, kadar pembebasan haba (ROHR), dan kadar kenaikan tekanan (ROPR) berbanding dengan bahan api petrol dan bahan api gas asli termampat tanpa penggunaan ruang pembakaran awalan. Kesimpulannya, kajian ini melaporkan bahawa ruang pembakaran awalan ini meningkatkan prestasi bahan api CNG hanya pada kelajuan enjin tinggi (2500 rpm) dan mengurangkan prestasi pembakaran CNG pada kelajuan enjin yang rendah.

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TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENT	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF SYMBOLS	xi
LIST OF ABBREVIATION	xiii
LIST OF APPENDICES	xv
LIST OF PUBLICATIONS	xvi
CHAPTER	
1 INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	3
1.3 Objectives	3
1.4 Scope	3
1.5 Hypothesis	4
2 LITERATURE REVIEW	5
2.1 Natural gas	5
2.2 Natural gas as alternative fuel	7
2.3 Performance of natural gas	8
2.4 Method for increasing the performance of natural gas	13
2.5 Pre combustion chamber	23
2.5.1 Pre Chamber with auxiliary fuelling	28
2.5.2 Pre chamber without auxiliary fuel	31
2.6 Summary	34
3 METHODOLOGY	35
3.1 Introduction	35
3.2 Equipment and apparatus	37
3.2.1 Small engine dynamometer	37
3.2.2 Compressed natural gas (CNG) kit	40
3.2.3 Pressure transducer	42
3.2.4 Crank Angle Encoder	46
3.2.5 Pre Chamber	48

3.3	Theoretical expression	51
3.3.1	Power and torque	51
3.3.2	Brake specific fuel consumption	52
3.3.3	Cylinder pressure	53
3.3.4	Temperature	54
3.3.5	Rate of heat release	55
4	RESULTS AND DISCUSSION	57
4.1	Comparison of performance between gasoline and CNG fuel without pre chamber	57
4.1.1	Power & Torque	57
4.1.2	Cylinder pressure	60
4.1.3	Rate of pressure rise	68
4.1.4	Temperature	75
4.1.5	Rate of heat release	82
4.2	Comparison of performance and combustion by CNG with pre chamber between normal CNG and gasoline	89
4.2.1	Power and Torque	89
4.2.2	Brake specific fuel consumption	92
4.2.3	Cylinder pressure	94
4.2.4	Rate of pressure rise	100
4.2.5	Temperature	106
4.2.6	Rate of heat release	112
5	CONCLUSION AND RECOMMENDATIONS	118
5.1	Conclusion	118
5.2	Recommendations	119
	REFERENCES	120
	APPENDICES	132

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Substances of natural gas and their volume in percentage	6
2.2	Properties of natural gas and gasoline	9
2.3	Findings obtained from the three methods of CNG injection	17
2.4	The differences of gas components in CNG and HCNG	20
2.5	Properties of different types of fuel engine used	22
3.1	Engine specifications	38
3.2	High pressure sensor model 112A05 specifications	43

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Statistics on registered CNG vehicles based on region.	2
2.1	The effect of volumetric efficiency and brake power for gasoline and methane	10
2.2	The profile for pressure versus crank angle	11
2.3	Effect of intake manifold pressure on power output	13
2.4	Advanced intake system	15
2.5	PSC spark plug injector	18
2.6	The effect of HCNG on the pressure inside cylinder	21
2.7	Ricardo Dolphin pre chamber	24
2.8	The location of the pre chamber orifice	25
2.9	Principle operation of pre chamber	26
2.10	PCC with auxiliary fuelling	27
2.11	Pre chamber without auxiliary fuelling	28
2.12	BPI pre chamber technical drawing	32
2.13	The focus area studied by Koji Yamanaka	33
3.1	Flow chart for research activities	36
3.2	Schematics diagram for the hydraulic dynamometer with CNG kit	39
3.3	The stage for switching between gasoline fuel and CNG fuel	41

3.4	High pressure sensor model 112A05	42
3.5	Recess mount	44
3.6	Flush mount	44
3.7	Sensor with water excess mount setup	46
3.8	Angle encoder disc	47
3.9	Angle encoder installation	47
3.10	Pre chamber	49
3.11	Installation of the pre chamber to the engine.	49
3.12	Cross-sectional view of the pre chamber and the engine block	50
3.13	Working principle of high pressure sensor.	53
4.1	Effect of different engine fuel on engine power at different engine speed	58
4.2	Effect of different fuel on engine torque at different engine speed	59
4.3	Detailed information concerning cylinder pressure	60
4.4	Comparison of cylinder pressure between gasoline and CNG at various engine speeds.	64
4.5	Comparison of cylinder pressure for gasoline fuel at various engine speeds	65
4.6	Comparison of cylinder pressure for CNG fuel at various engine speeds	65
4.7	Detailed view for rate of pressure rise result	68
4.8	Effects of CNG and gasoline on the rate of pressure rise at various engine speed	71
4.9	Comparison of rate of pressure rise for gasoline fuel at various engine speeds	72
4.10	Comparison of rate of pressure rise for CNG fuel at various engine speeds	72
4.11	Detailed view of temperature result	75
4.12	Effects of gasoline and CNG fuel on temperature at different engine speed	79

4.13	Comparison of temperature for gasoline fuel at various engine speeds	79
4.14	Comparison of temperature for CNG fuel at various engine speeds	80
4.15	Detailed view rate of heat release result.	82
4.16	Effects of gasoline fuel and CNG fuel on rate of heat release at various engine speed.	86
4.17	Comparison of rate of heat release for gasoline fuel at various engine speeds	87
4.18	Comparison of rate of heat release for CNG fuel at various engine speeds	87
4.19	Effect of CNG pre chamber on power at various engine speed	90
4.20	Effect of CNG pre chamber on torque at various engine speed	91
4.21	Effect of engine speed on brake specific fuel consumption for all case studies	93
4.22	Detailed view of cylinder pressure data	94
4.23	Cylinder pressure data for CNG fuel with pre chamber at various engine speeds	97
4.24	Comparison of cylinder pressure for CNG fuel with pre chamber at various engine speeds	98
4.25	Detailed view on rate of pressure rise result.	100
4.26	Effect of pre chamber with CNG fuel on rate of pressure rise	103
4.27	Comparison of rate of pressure rise for CNG fuel with pre chamber at various engine speeds	104
4.28	Detailed view of temperature results	106
4.29	Effect of CNG fuel with pre chamber at various engine speed	109

4.30	Comparison of temperature for CNG fuel with pre chamber at various engine speeds	110
4.31	Detailed view of result for rate of heat release	112
4.32	Effect and comparison results on rate of heat release for both types of fuels	115
4.33	Comparison of rate of heat release for CNG fuel with pre chamber at various engine speed	116

LIST OF SYMBOLS

n_v	Volumetric efficiency
ρ_a	Density of air at engine inlet
V_d	Engine displacement
k	Power stroke per engine revolution
N	Engine speed
m_a	Mass flow rate
W	Wiebe function
P_0	Pressure
V_0	Volume
CR	Compression ratio
β	Dimensionless parameter
J	Work done
V_s	Swept volume
Nm	Torque
P	Pressure
R	Gas constant
T	Temperature
q	Polarizes charge

θ	Crank Angle (deg)
δQ_{hr}	Change in chemical energy released from the fuel
dU	Change in internal energy of the mass in control volume
δW	Elementary Work
δQ_{ht}	Heat loss to cylinder wall
$\frac{dP}{dT}$	Pressure change rate
$\frac{d\varepsilon}{dT}$	Rate of deformation
$\frac{dp}{d\theta}$	Rate change of pressure
$\frac{dV}{d\theta}$	Rate change of volume
$\frac{dQ}{d\theta}$	Rate of heat release
c_p	Specific heat at constant pressure
c_v	Specific heat at constant volume
γ	Specific heat ratio

LIST OF ABBREVIATIONS

RM	Ringgit Malaysia
RON	Research Octane Number
CNG	Compressed Natural Gas
NGV	Natural Gas Vehicle
TDC	Top Dead Centre
EGR	Exhaust Gas Recirculation
IVC	Intake Valve Close
BMEP	Brake Mean Effective Pressure
PSC	Partial Stratifications
BSFC	Brake Specific Fuel Consumption
LML	Lean Misfire Limits
MBT	Maximum Brake Torque
HCNG	Hydrogen Blended Compressed Natural Gas
IC	Internal Combustion
BDC	Bottom Dead Centre
PCC	Pre Combustion Chamber
JPIC	Jet Plume Injection and Combustion
HAJI	Hydrogen Assisted Jet Ignition
HFJI	Hydrogen Flame Jet Ignition
PJC	Pulsed Jet Combustion

APIR	Auto-inflammation Pilot'ee Par Injection De Radicaux
ECU	Engine Control Unit
IMEP _n	Net Indicated Mean Effective Pressure
IMEP _g	Gross Indicated Mean Effective Pressure
PMEP	Pump Mean Effective Pressure
ROHR	Rate of Heat Release
ROPR	Rate of Pressure Rise

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	SAE International Standard (J1349)	132
B	Technical drawing for water cooled adaptor	134
C	Technical drawing for pre chamber	136
D	Calibration report for high pressure sensor	139

LIST OF PUBLICATIONS

M.S. Ali, Musthafah M.T., A.M. Mohd Shafei, R.A. Bakar. *Simulation of Single Cylinder Engine Fuel with Alternative Fuel by Using Available Software*, International Review of Mechanical Engineering (IREME), Vol.8, No.4, July 2014, pp. 798-802.

Musthafah M.T., **M.S. Ali**, M.A. Salim, Rosli A. Bakar, A.M. Fudhail, M.Z. Hassan, Abdul Muhaimin M.S. *Performance Analysis of A Spark Ignition Engine Using Compressed Natural Gas (CNG) as Fuel*. 2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014. Proceeding of Energy Procedia, Vol.68 (2015), pp. 355-362.

M.S. Ali, M.T. Musthafah, A.M. Mohd Shafei, A.M.T. Khairil, N.F.M. Nor, R.A. Bakar. *Performance of Compressed Natural Gas (CNG) Engine with Pre Chamber*. Proceeding of Mechanical Engineering Research Day, March 2016, pp. 7-8.

CHAPTER 1

INTRODUCTION

1.1 Background

The shortage of fossil fuel supply at present is a worldwide phenomenon. This situation has led to an increase in price for fossil fuel, especially for gasoline fuel and diesel. Unfortunately, the same situation had been fallen upon Malaysia as the price of gasoline fuel had increased during February 2015 until Mac 2015 from RM 1.70 into RM 1.95 for RON 97. Therefore, alternative fuel has been in more demand among users. With that, the natural gas is seen as the best alternative fuel due to its large storage and low cost compared to other alternative fuels.

Moreover, the implementation of natural gas into automotive application in internal combustion engine has been found to increase day by day. The natural gas in internal combustion engine is called compressed natural gas (CNG) or natural gas vehicle (NGV). The statistics for the usage of CNG in internal combustion engine application is portrayed in Figure 1.1:

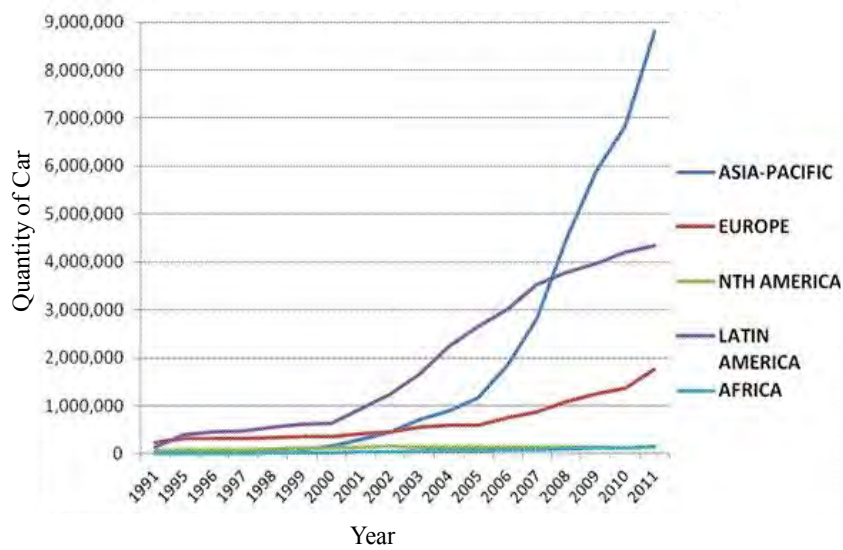


Figure 1.1: Statistics on registered CNG vehicle based on region. (www.iangv.org)

[accessed date 4/5/2016]

Based on Figure 1.1, the statistics of registered CNG vehicles has increased, especially in the Asia region. This shows that the demand of this natural gas as an alternative fuel is not only focused on the current region, but also worldwide at present.

Moreover, the application of this natural gas in the automotive area has led to a decrease in the emission produced compared to gasoline and diesel. In fact, one of the many advantages offered by this natural gas is emission reduction in CO₂, HC, and NO_x (Engerer and Horn, 2010; Jahirul *et al.*, 2010; Jääskeläinen and Wallace, 1993; Ma *et al.*, 2009).

However, the natural gas has a disadvantage concerning performance by the engine when the natural gas is applied as a power source. In terms of performance drop, the natural gas causes the engine drop in power, torque, brake, and specifically fuel

consumption (Jääskeläinen and Wallace, 1993; Gimelli *et al.*, 2008; Ghazal, 2013). With that, many methods have been suggested to overcome the lack of performance.

1.2 Problem statement

Application of CNG fuel into spark ignition engine produced lower performance compared to gasoline fuel (Gimelli *et al.*, 2008). In order to overcome this performance drop, the engine needs modification. The modifications are focused in engine geometry and engine firing timing. (Sera *et al.*, 2003). Besides engine modification, usage of pre chamber also can improve CNG performance. However, usage of pre chamber is only best for engine with injector, while CNG is injected directly into combustion chamber (Attard and Parsons, 2010).

1.3 Objectives

The objectives of the research are as follows:

- a. To investigate the effect of pre chamber on power, torque and, brake specific fuel consumption of single cylinder spark ignition compressed natural gas engine.
- b. To analyse the combustion of spark ignition engine using CNG with pre chamber.

1.4 Scope

The scopes of this study are as follows:

- a. Apply the natural gas fuel into single cylinder spark ignition engine without engine modification.
- b. Study and compare the performance and combustion by natural gas fuel with gasoline fuel.

- c. Apply the pre chamber into single cylinder spark ignition engine.
- d. Study the effect of this pre chamber into performance and combustion of natural gas fuel.
- e. Compared the effect of this pre chamber into performance and combustion of natural gas fuel with gasoline fuel.

1.5 Hypothesis

Compressed natural gas is rather well-known for it generates lower performance compared to gasoline fuel or diesel fuel. Thus, the focus of this study is to determine the performance of compressed natural gas and the combustion in single cylinder spark ignition engine. The engine types used in this study is natural aspirated or in other words, engine operated with a carburettor.

Moreover, previous work was already done for this compressed natural gas performance and combustion either an engine with carburettor or engine with injector. The result from the application of this compressed natural gas had been used in the study to look into the effect of pre chamber on compressed natural gas fuel. Besides, many researchers have focused on pre chamber with injector and combined with modification of injection timing.

In this study, nevertheless, the focus is on the effect of pre chamber to identify if it suitable with engine operated by carburettor without changing any firing timing. Furthermore, the main target of this pre chamber is to increase the compressed natural gas performance. In addition, the effect of combustion for compressed natural gas when the pre chamber installed to a single cylinder engine was also investigated.