DUAL FUEL ENGINE PERFORMANCE AND EMISSION CHARACTERISTICS USING COMBINATION OF NATURAL GAS AND BIODIESEL BLENDS

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Dedicated to my beloved parents Stephen Kiri Anak Billiam and Subing Anak Dusun/Duros, my siblings and my beloved Ainul Najwa Sazali

Thanks for your love and endless encouragement

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ABSTRACT

Diesel dual fuel (DDF) engine is an alternative that has several potential advantages such as cleaner engine emission, fuel flexibility, more economical and better engine efficiency. Diesel and compressed natural gas (CNG) are commonly employed to operate the DDF engine. The substitution of diesel with biodiesel is believed to be able to achieve better emission results. Utilization of CNG and biodiesel in DDF engines can be considered as one of the optimum alternative solutions for fuel economy and can easily achieve auto ignition temperature. Several types of fuel namely, diesel, biodiesel, combination of diesel and natural gas as well as combination of biodiesel and natural gas were employed to compare their effects on the engine performance and emission. Six-cylinder 6.7L engines with auto-load connected to engine-dyno system were employed during the experimental tests. At maximum speed, results showed that increasing of biodiesel percentage in pilot fuel compound resulted in engine power reductions of approximately 132 hp compare to 139 hp recorded by industrial diesel fuel. Air to fuel ratio of industrial diesel and CNG recorded the highest result that was 3.94 at maximum speed compared to 20 % biodiesel blend and industrial diesel without CNG. Carbon dioxide, carbon monoxide and hydrocarbon emissions were reduced by 29 %, 35 % and 37 %, respectively at 2500 rpm and further reduced for engine operating without CNG. However, higher biodiesel blends in fuels had contributed in increasing of nitrogen oxide emission up to 321 ppm at maximum engine speed. Results recorded in this study proved that dual fuel engine provided significant advantages toward better engine performance and emission at maximum engine speed. The presence of biodiesel and CNG boosted the efficiencies of dual fuel engine system while providing cleaner fuels.

ABSTRAK

Enjin bahan api duaan diesel (DDF) merupakan satu alternatif yang mempunyai beberapa kelebihan seperti menghasilkan pelepasan enjin yang bersih, fleksibiliti bahan api, lebih menjimatkan dan kecekapan enjin yang lebih baik. Diesel dan gas asli termampat (CNG) merupakan bahan api yang biasa digunakan untuk mengendalikan enjin. Penggantian diesel dengan biodiesel dipercayai mampu untuk mencapai keputusan pelepasan yang lebih baik. Penggunaan CNG dan biodiesel di dalam enjin DDF merupakan salah satu penyelesaian optimum untuk bahan api yang ekonomi dan mudah mencapai suhu nyalaan kendiri. Beberapa jenis bahan api iaitu diesel, biodiesel, kombinasi diesel dan gas asli dan juga kombinasi biodiesel dan gas asli telah digunakan untuk membuat perbandingan kesan bahan api ke atas prestasi enjin dan kuantiti pelepasan enjin. Enjin enam silinder 6.7L dengan beban automatik yang disambung pada sistem enjin-*dyno* telah digunakan semasa ujikaji. Pada kelajuan maksimum, keputusan ujian menunjukkan peningkatan peratus biodiesel dalam sebatian bahan api rintis mengakibatkan pengurangan kuasa enjin ke lebih kurang 132 hp berbanding 139 hp oleh bahan api industri. Nisbah udara kepada bahan api bagi diesel industri dan CNG mencatatkan keputusan tertinggi iaitu 3.94 pada kelajuan enjin maksimum berbanding adunan 20 % biodiesel dan diesel industri tanpa CNG. Pelepasan karbon dioksida, karbon monoksida dan hidro karbon menurun masing-masing sebanyak 29 %, 35 % dan 37 % pada kelajuan 2500 rpm dan pengurangan selanjutnya untuk enjin beroperasi tanpa CNG. Walau bagaimanapun, adunan biodiesel dalam bahan api yang lebih tinggi telah menyebabkan peningkatan pelepasan nitrogen oksida sehingga 321 ppm pada kelajuan enjin maksimum. Keputusan yang dicatatkan dalam kajian ini membuktikan bahawa enjin bahan api duaan memberikan kelebihan yang ketara kepada prestasi enjin dan pelepasan yang lebih baik pada kelajuan enjin maksimum. Kehadiran biodiesel dan CNG meningkatkan kecekapan sistem enjin bahan api duaan di samping menyediakan bahan api yang lebih bersih.

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LIST OF SYMBOLS

Symbol		Description	Unit
r	-	Compression ratio	
k	-	Ratio of specific heats	
η	-	Efficiency	
D	-	Cylinder bore (m)	m
m	-	Mass (kg)	kg
$\dot{m}$	-	Mass flow rate (kg/h)	kg/h
P	-	Pressure (Pa)	Pa
Q	-	Heat (J)	J
R	-	Specific gas constant	J/ (kg.K)
T	-	Absolute temperature (K)	K
V	-	Volume (m3)	m^3
αc	-	Constant	
λ	-	Thermal conductivity	W/ (m.K)
φ	-	Equivalence ratio	
g	-	Gas	
γ	-	Palm oil (L)	
β	-	Diesel Oil (L)	
θ	-	Crank angle	
$\dot{m}1$	-	Mass flows	
$\dot{h}1$	-	Enthalpy flows	J/s
u	-	Internal energy	J
Q	-	Transferred heat	Watt
ω	-	Rotation speed	rad/s
b	-	Burned zones	
u	-	Unburned zones	
x	-	Fraction of the blend	
ε	-	Stoichiometric fuel	

xH_2O	-	Mole fraction of water in the fuel
yn	-	Mole fraction of each component
xn	-	Mass fraction of component n in unburned blend
xn	-	Mass fraction of component n in burned blend
r	-	Compression ratio
l	-	Length of the connecting rod
S	-	Piston stroke
$\Delta\theta$	-	Duration of combustion
θi	-	Angle in which the combustion start
Wi	-	Work
$sfci$	-	Specific consumption of palm oil in the blend
Q_{LHV}	-	Lower calorific value of fuel
UR	-	Uncertainty of the measured quantity R
xn	-	Independent variables with measured uncertainties
Uxn	-	Error limits of measured parameters

LIST OF ABBREVIATIONS

AFR	-	Air to Fuel Ratio
ANG	-	Adsorbed Natural Gas
ASTM	-	American Standard Testing Method
B5	-	A Blend of 5 % Palm Oil Biodiesel and 95 % Diesel
B10	-	A Blend of 10 % Palm Oil Biodiesel and 90 % Diesel
B15	-	A Blend of 15 % Palm Oil Biodiesel and 85 % Diesel
B20	-	A Blend of 20 % Palm Oil Biodiesel and 80 % Diesel
B100	-	100 % Palm Oil Biodiesel
BMEP	-	Brake Mean Effectives Pressures
BSFC	-	Brake Specific Fuel Consumption
CH_4	-	Methane
CI	-	Compressed Ignition
CNG	-	Compressed Natural Gas
CNG-DDF	-	Compressed Natural Gas – Dual Diesel Fuelled
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CPO	-	Crude Palm Oil
CR	-	Compression Ratio
DDF	-	Dual Diesel Fuelled
DI	-	Direct Injection
ECU	-	Electronic Control Unit
EGR	-	Exhaust Gas Recirculation
EPA	-	Environmental Protection Agency
EU	-	European Union
FAME	-	Fatty Acid Methyl Ether
GASTEG	-	Gas Technology Centre
GHG	-	Greenhouse Gas
GMB	-	Gas Malaysia Bhd.

GJ	-	Giga Joule
HC	-	Unburned Hydrocarbons
IEA	-	International Energy Agency
JAMA	-	Japan Automobile Manufacturers Association
Kg/m^3	-	Kilogram Per Cubic Meter
JPJ	-	Jabatan Pengangkutan Jalan
LPG	-	Liquefied Petroleum Gas
NGV	-	Natural gas Vehicle
MW	-	Megawatt
NaOH	-	Sodium Hydroxide
NIOSH	-	National Institute of Occupational Safety Health
NO	-	Nitric Oxide
NO_2	-	Nitrogen Dioxide
NO_x	-	Nitric Oxide
O_2	-	Oxygen
OEM	-	Original Equipment Manufacturer
PM	-	Particulate matter
PPM	-	Parts per million (volume)
PRC	-	People’s Republic of China
PUSPAKOM	-	Pusat Pemeriksaan Kenderaan Berkomputer
RE	-	Renewable Energy
RON	-	Research octane number
RPM	-	Revolution per minute
RM	-	Ringgit Malaysia
SEC	-	Specific Energy Consumption
SFC	-	Specific Fuel Consumption
SO_2	-	Sulphur Dioxide
SOF	-	Soluble Organic Fraction
TDC	-	Top-Dead Centre
USD	-	United State Dollar
EPU	-	Economic Planning Unit
US	-	United States of America
UTM	-	Universiti Teknologi Malaysia
WHO	-	World Health Organisation

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, the world is struggling towards producing more environmental friendly fuels for daily use. The alternative gaseous fuels in engines applied for the purpose of power production has increased globally (Papagiannakis and Hountalas, 2000). The use of natural gas as supply system in diesel engines presently has gained considerable attention due to high demand on engine efficiencies in large vehicle such as buses and trucks (Dong *et al*., 2001).

In Malaysia, the government started to allocate budget as an investment in industrial waste and the degradation of urban environment. Recent years, pollution of air and water caused by industrial wastes has reached its peak level of criticality (Rafia et al., 2003). These lead to several problems in many areas such as human health, agriculture crops, forest species, and ecosystem. Frequent checked by monitoring data and studies on ambient air quality show that some of the air pollutants in several large cities are increasing and failed to achieve acceptable levels according to the national ambient air quality standards (Rafia *et al*., 2003). Environmental concern about the acid rains and smog during that time also become a reason why the fuels must be replaced by other energy carrier. It is generally known that, almost all vehicles in the world are powered by gasoline and diesel which both extracted from crude oils and will eventually produce pollutants after combustion. Thus, in considering future environmentally friendly fuel, the new energy carrier such as methanol, natural gas and biodiesel were explored.

Dual fuel diesel engine can be considered as having capability to achieve low pollution option for diesel engine by employing natural gas and biodiesel instead of common typical diesel extracted from crude oils. Dual fuel engines powered by natural gas and biodiesel offer another additional advantage that do not require major modification in engines (Kiyoshi and Koji, 2007). The used of biodiesel which offers potential reductions in a life cycle of carbon dioxide as well as hydrocarbon emissions also directly contribute in saving our environment. Biodiesel is a renewable energy extracted from vegetable oils with oxygenated fuel characteristics (André and Samantha, 2009). Based on few previous studies by André and Samantha, (2009), the compositions of fatty acid methyl esters (FAME) in biodiesel fuels depend on the fatty acids component in the feedstock. When biodiesel fuels used as an ignition fuel for dual fuel diesel engines, it is necessary to take into account the effect or how fatty acid methyl esters influence the engine performance, and exhaust emissions (John and Robert, 2009). In addition, the application of diesel dual fuel also strongly supported by natural gas which is able to produce low polluted emission added with its availability in a several part of the world.

1.2 Problem Statement

Increasing number of vehicles especially trucks in a developed countries leads to increasing of pollution levels. For example in Malaysia, engines which are operated using diesel fuels were recorded as the main contributor of air pollutants. As such, various types of greenhouse gases are still freely emitted to the environment (The Economic Planning Unit, 2006). As a developed country with industrial sector rises nationwide, trucks are the most common convenience transportation for industrial products. These diesel trucks are operated by diesel fuel with high pollutant level emitted from the engine combustion. Nowadays, most of the big trucks in Malaysia are equipped with dual fuels engine system to optimize the fuel consumption and to reduce black smoke which cause air pollution. Common dual fuels engine system in Malaysia are powered by diesel and natural gas. However, by using diesel to operate the engines, it is still not the best idea in order to reduce the pollution levels emitted to environment. Diesel fuels used in engines can emit pollutant such as nitrogen oxide, carbon dioxide, and other types of hydrocarbons (André and Samantha, 2009).

There were various studies conducted previously by other researchers to measure the similar parameters (John and Robert, 2009), (Kawasaki and Yamane, 2007), (Jian *et al.*, 2001), however the constraint in types of engine used which is small or single cylinder engine seem to be limitation to the results obtained. Small engine capacity will shows different number or level measurement of each parameter which then become constraint to indicate the actual measurement of pollutants emitted by big truck on the road.

1.3 Significant of the Study

The study is intended to evaluate the emission characteristic of the DDF engine and its contributing impact towards the environment. The use of several types of biodiesel blends in the engine as well as injection of Natural Gas is expected to explore possibilities of acquiring understanding of engine and emission performance based on multiple blending fuels. This would be useful in establishing correlation of fuel blends against engine emission and performance. Continuous effort in previous research had been carried out for the past few years to obtain the optimum desired result in operating conventional diesel engine using combination of Natural Gas and Biodiesel. Opportunity by applying the actual trucks engine in this study will represent the actual field measurement. The impacts of the biodiesel fueling to the engine performance such as engine power, torque, and air to fuel ratio and maximum speed also need to be considered since biodiesel is found to have lower calorific value as compared to the common diesel fuel. In this study, it is proven that the employment of Biodiesel as a pilot fuel and Natural Gas as main fuel could directly contributes to the cleaner engine emission without jeopardizing the engine performance.

1.4 Objective

i. To determine the emission characteristic of the various diesel dual fuel engine testing when several combination of waste cooking oil based biodiesel blends and natural gas are applied to the engine.

ii. To evaluate the engine performance such as horse power, engine torque and air to fuel ratio of the diesel dual fuel engine when biodiesel-natural gas fueling applied.

1.5 Scope of study

In order to achieve the objectives, the following scopes are identified:

i. Utilize diesel engine Hino H07C 6-Cylinder 6728cc as a testing engine in this study. Minor modifications on the engine are conducted to suit the dual fuel injection system without comprehensive natural gas injection program and software mapping.

ii. Biodiesel applied in this study was extracted from waste cooking oil supplied by Forest Research Institute of Malaysia (FRIM) which were blended into B5, B10, B15 and B20.

iii. Industrial diesel applied in this study was directly supplied from refinery with zero additive and biodiesel added.

iv. Perform engine test run by employing industrial diesel, biodiesel and natural gas in dual fuel system operation. The engine test run were repeatedly conducted to obtain thorough average results.

v. Study of the effect on the engine emission by using three types of fuels mentioned and the emission monitored and recorded thoroughly to achieve the best result for this study.

vi. Investigate the engine performances characteristics operated by variety of driving fuels.

vii. Perform comparative study on the operability of the dual fuel engine system operated using industrial diesel and various types of biodiesel blends.

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APPENDIX A

ENGINE TESTING PROCEDURE

1. The oil tank was filled with B5 fuel and connects the natural gas line to the gas injector rail.
2. Ensure that the engine is connected to the dynamometer and emission analyzer.
3. The gas was inserted into the engine.
4. The engine and dynamometer were warmed up for 30 minutes and 15 minutes respectively.
5. The speed of the engine tuned up to 500rpm.
6. The data for amount of NO_x, CO, CO_2 and HC from the emission analyzer were recorded.
7. Step 4 and step 5 were repeated for various speeds which are 1000 rpm, 1500 rpm, 2000 rpm, and 2500 rpm.
8. The throttle released and let the engine idle for 10 minutes.
9. The speed of the engine was increase up to 500rpm and releases the throttle after 5 minutes.
10. The data for Engine Power and Engine Torque from the dynamometer were recorded.
11. Step 8 and step 9 were repeated for various speeds which are 1000 rpm, 1500 rpm, 2000 rpm, and 2500 rpm.
12. The throttle released and let the engine idle for 10 minutes.
13. The throttle knob slowly pulled to the maximum level for 1 minute and release.

14. The data for the maximum RPM obtained from dynamometer were recorded.

15. The engine was switched off and let it cool for at least 1 hour.

16. The gas flow to the engine was shut off.

17. Remaining fuel inside the oil tank was drained.

18. Step 1 until step 17 was repeated using B10, B15 and B20.