EXPERIMENTAL AND PREDICTION MODEL OF LOW COMPRESSION MARINE DIESEL ENGINE FUELLED WITH PALM BIODIESEL BLENDS

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Enjin diesel marin menyediakan sumber kuasa utama untuk pengangkutan laut, tetapi pelepasan dari enjin adalah penyumbang besar kepada pencemaran udara terutamanya di kawasan pelabuhan dan pesisir pantai. Pengenalan bahan api alternatif seperti biodiesel dilihat sebagai penyelesaian yang menjanjikan untuk mengurangkan pelepasan gas berbahaya dari enjin. Namun, kajian bahan bakar biodiesel terhadap enjin diesel marin masih terhad di mana kebanyakan kajian terdahulu menumpukan pada enjin nisbah mampatan tinggi. Bagaimana kesan biodiesel terhadap prestasi enjin marin mampatan rendah tidak diketahui dan perlu disiasat untuk menentukan kesesuaiannya. Oleh itu, projek ini bertujuan untuk mengkaji kesan campuran biodiesel sawit pada enjin diesel marin mampatan rendah yang memfokuskan kepada ciri-ciri pembakaran bahan bakar, variasi kitaran enjin, prestasi enjin dan pelepasan ekzos. Selain daripada ujikaji, pendekatan dengan menggunakan model simulasi rangkaian neural buatan juga dibangunkan untuk meramalkan parameter prestasi enjin. Ujian enjin telah dilakukan keatas enjin diesel marin empat lejang, enam silinder sebaris (Cummin NT-855M) di makmal. Enjin ini mempunyai nisbah mampatan 14.5:1 dan isipadu sesaran sebesar 14 liter. Semua ujian dilakukan di bawah keadaan mantap pada beban enjin 10%, 30% dan 50%, dengan mengubah kelajuan enjin diantara 800–1600 rpm dan menggunakan nisbah campuran biodiesel sawit yang berbeza (10%, 20% dan 30%). Hasil ujian mendedahkan bahawa campuran biodiesel sawit berjaya digunakan dalam enjin diesel marin mampatan rendah dan setanding dengan bahanapi diesel. Peningkatkan kepekatan biodiesel sawit dalam campuran telah mengurangkan kadar pelepasan haba dan kadar peningkatan tekanan sehingga 2.62% dan 2.77% masing-masing, semasa proses pembakaran. Progres dalam pecahan jisim pembakaran menunjukkan bahawa tempoh pembakaran menjadi lebih panjang sebanyak 1.50–2.14 °CA berbanding bahanapi diesel. Nilai pemanasan rendah dan kelikatan tinggi pada biodiesel sawit ditambah dengan silinder mampatan rendah telah mengurangkan kadar pembakaran premix, dengan itu memanjangkan tempoh pembakaran biodiesel. Kandungan tenaga yang kurang dalam campuran biodiesel sawit telah menurunkan sedikit kecekapan terma enjin (8.31%). Namun, di sisi positifnya, penggunaan campuran biodiesel sawit dalam enjin diesel marin mampatan rendah telah mengurangkan pelepasan gas berbahaya nitrogen oksida dan karbon monoksida sehingga 13.02% dan 66.67%, masing-masing. Peningkatan peratusan biodiesel sawit dalam campuran juga mengurangkan variasi kitaran enjin di mana campuran B30 menghasilkan variasi paling minima di antara bahan api yang diuji. Plot spektrum kuasa wavelet menunjukkan ayunan kekerapan yang rendah dalam variasi IMEP apabila beroperasi dengan campuran biodiesel sawit. Model ramalan enjin yang menggunakan kaedah rangkaian neural buatan menghasilkan korelasi yang sangat baik diantara data ramalan dan eksperimen seperti yang ditunjukkan oleh nilai R yang tinggi iaitu 0.9987–0.9999. Model rangkaian neural buatan sesuai untuk digunakan dalam masalah bukan linear kerana ia mampu memberikan ramalan prestasi enjin yang tepat dengan kesalahan yang minima (0.20–2.79%). Ujikaji dan model ramalan menggunakan campuran biodiesel sawit dalam enjin diesel marin mampatan rendah yang tidak dimodifikasi telah menyumbang kepada bidang pengetahuan dalam memahami ciri-ciri pembakaran dan prestasi enjin tersebut. Pengurangan dalam kadar pembakaran premixed, variasi kitaran enjin dan pelepasan ekzos yang diperoleh daripada campuran biodiesel sawit adalah penemuan yang paling penting dalam kajian ini.

ABSTRACT

Marine diesel engines provide primary power sources for sea transportation, but emissions from the engines are a major contributor to air pollution especially in port and coastal areas. The introduction of alternative fuels such as biodiesel is seen as a promising solution to reduce harmful gas emission from the engine. However, biodiesel fuel studies on marine diesel engines are still limited where most previous studies focus on high compression ratio engines. How the biodiesel effect on the performance of the low compression marine engine is unknown and should be investigated in order to determine its suitability. Therefore, this project aims to investigate the effects of palm biodiesel blends on low compression marine diesel engines focusing on fuel combustion, engine cyclic variations, engine performance and emissions characteristics. Apart from experiment, an approach by using artificial neural network simulation model was also developed to predict the performance parameters. Engine testing was performed using four strokes, in-line six-cylinder marine diesel engine (Cummin NT-855M) in the laboratory. The engine has 14.5:1 compression ratio and 14 litres displacement volume. All tests were performed under steady-state condition at 10%, 30% and 50% engine loads by varying the engine speed between 800–1600 rpm and fuelled with different palm biodiesel blends (B10, B20 and B30). The test results reveal that palm biodiesel blends are successfully used in low compression marine diesel engine and comparable to diesel fuel. Increase the concentration of palm biodiesel in blends has reduced the rate of heat release and the rate of pressure rise up to 2.62% and 2.77% respectively, during the combustion proses. Mass fraction burned progress indicated the combustion duration was longer by 1.50–2.14 °CA relative to diesel fuel. Low heating value and high viscosity of palm biodiesel coupled with low compression cylinder have reduced the premix combustion rate hence prolonged the biodiesel combustion duration. Lesser energy content in palm biodiesel blends has slightly reduced the engine thermal efficiency (8.31%). However, on the positive side, the use of palm biodiesel blends in low compression marine diesel engine has reduced harmful gas emissions of nitrogen oxides and carbon monoxide up to 13.02% and 66.67%, respectively. Increased palm biodiesel percentage in the blend also lowered the engine cyclic variations where the B30 blend produces the minimum variations among the tested fuels. The wavelet power spectrum plot shows lower frequency oscillations of IMEP when operated with palm biodiesel blends. The engine prediction model of using artificial neural network approach provides excellent correlation between predicted and experimental data as indicated by higher R-value of 0.9987–0.9999. An artificial neural network model is suitable for use in non-linear problems as the model provides accurate engine performance prediction with minimal errors (0.20–2.79%). Experimental and prediction model of using palm biodiesel blends in the unmodified low compression marine diesel engine has contributed to the body of knowledge in understanding the combustion and performance behaviours of the marine engine. Reduction in premixed combustion rate, engine cyclic variations and exhaust emission obtained from palm biodiesel blends are the most important findings in this study.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

a	Crank radius
A	Area
b	Bias value
B	Cylinder bore diameter
c	Specific heat
c_p	Specific heat at constant pressure
c_v	Specific heat at constant volume
C	Absolute gas velocity
l	Connecting rod length
$\dot{m}$	Fuel mass
n	Wavelet time index
N	Crankshaft rotational speed, cycle number, total number of data
o	Output value
p	Cylinder pressure
p_{max}	Peak cylinder pressure
P	Power
q	Heat amount
Q	Heat transfer
Q_{HV}	Fuel heating value
Q_n	Net heat release
Q_{out}	Heat rejected
r	Radius
R	Coefficient of correlation
s	Distance between crank axis to piston pin
t	Target value
T	Temperature, Torque
V	Cylinder volume
V_c	Clearance volume
V_d	Displaced cylinder volume
V_t	Total cylinder volume
w	Weight value

W_{in}	Work input
W_{out}	Work output
W_n	Wavelet transform
x	Input value
Y	Output value
β	Equation coefficient
γ	Specific heat ratio
η	Time parameter
θ	Crank angle
ν	Kinematic viscosity
π	Normalisation factor
ρ	Density
σ	Standard deviation
φ	Activation function
ψ	Non-dimensional wavelet
ω	Wave number

LIST OF ABBREVIATIONS

ANN	Artificial neural network
ANOVA	Analysis of variance
ASTM	American Society of Testing Materials
ATR	Attenuated total reflection
BDC	Bottom dead centre
BSFC	Brake specific fuel consumption
BP	Back-propagation
BTE	Brake thermal efficiency
CA	Crank angle
CO	Carbon monoxide
CO_2	Carbon dioxide
COI	Cone of influence
COV	Coefficient of variation
CWT	Continuous wavelet transformation
DI	Direct injection
EGT	Exhaust gas temperature
EN	European Norms
FAME	Fatty acid methyl ester
FFNN	Feed-forward neural network
FTIR	Fourier transform infrared
GHG	Greenhouse gases
GWS	Global wavelet spectrum
HC	Hydrocarbon
IDI	Indirect injection
IMEP	Indicated mean effective pressure
IMO	International Maritime Organization
MARPOL	Marine pollution
MCR	Maximum continuous rating
MFB	Mass fraction burned
MLP	Multi-layer perception
MPa	Megapascal

MRE	Mean relative error
MSE	Mean square error
NBP	National Biofuel Policy
NDIR	Non-dispersive infrared
NO_x	Nitrogen oxides
PFAD	Palm fatty acid distillate
PFAME	Palm fatty acid methyl ester
PM	Particulate matter
rpm	Revolutions per minute
RoHR	Rate of heat release
RoPR	Rate of pressure rise
SOC	Start of combustion
SOI	Start of injection
SO_x	Sulphur oxides
TDC	Top dead centre
ULSD	Ultra-low sulphur diesel
VDC	Voltage direct current
WPS	Wavelet power spectrum

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