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

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UNIVERSITI MALAYSIA PAHANG
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.

_____________________________________________________
(Supervisor’s Signature)

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Date         :
STUDENT’S DECLARATION

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.

________________________________________
(Student’s Signature)

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CHE WAN MOHD NOOR BIN CHE WAN OTHMAN

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In the name of Allah, the Most Gracious, the Most Merciful. All praises be to Allah, the Lord of the World; peace and blessings of Allah be upon the noblest of the Prophets and Messengers, our Prophet Mohammed and upon his family, companions and those who follow him until the last day.

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Enjin diesel marin menyediakan sumber kuasa utama untuk pengangkutan laut, tetapi pelepasan dari enjin adalah penyumbang besar kepada pencemaran udara terutama di kawasan pelabuhan dan pesisir pantai. Pengenalan bahan api alternatif seperti biodiesel dinilai sebagai penyelesaian yang menjanjikan untuk mengurangi pelepasan gas berbahaya dari enjin. Namun, kajian bahan bakar biodiesel terhadap enjin diesel 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 komponen biodiesel 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 ke atas enjin diesel marpat empat lejang, enam silinder sebaris (Cummin NT-855M) di makmal. Enjin ini mempunyai nisbah mampatan 14.5:1 dan isipadu sebaris sebesar 14 liter. Semua ujian dilakukan di bawah keadaan mantap pada beban enjin 10%, 30% dan 50%, dengan mengubah kelajuan enjin di antara 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. Peningkatan 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 kecepatan termal 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 minim 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 di antara 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 minim (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 pengetahunan 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 processes. 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.
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<td>Artificial neural network</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<td>ASTM</td>
<td>American Society of Testing Materials</td>
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<td>ATR</td>
<td>Attenuated total reflection</td>
</tr>
<tr>
<td>BDC</td>
<td>Bottom dead centre</td>
</tr>
<tr>
<td>BSFC</td>
<td>Brake specific fuel consumption</td>
</tr>
<tr>
<td>BP</td>
<td>Back-propagation</td>
</tr>
<tr>
<td>BTE</td>
<td>Brake thermal efficiency</td>
</tr>
<tr>
<td>CA</td>
<td>Crank angle</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COI</td>
<td>Cone of influence</td>
</tr>
<tr>
<td>COV</td>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>CWT</td>
<td>Continuous wavelet transformation</td>
</tr>
<tr>
<td>DI</td>
<td>Direct injection</td>
</tr>
<tr>
<td>EGT</td>
<td>Exhaust gas temperature</td>
</tr>
<tr>
<td>EN</td>
<td>European Norms</td>
</tr>
<tr>
<td>FAME</td>
<td>Fatty acid methyl ester</td>
</tr>
<tr>
<td>FFNN</td>
<td>Feed-forward neural network</td>
</tr>
<tr>
<td>FTIR</td>
<td>Fourier transform infrared</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gases</td>
</tr>
<tr>
<td>GWS</td>
<td>Global wavelet spectrum</td>
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<tr>
<td>HC</td>
<td>Hydrocarbon</td>
</tr>
<tr>
<td>IDI</td>
<td>Indirect injection</td>
</tr>
<tr>
<td>IMEP</td>
<td>Indicated mean effective pressure</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>MARPOL</td>
<td>Marine pollution</td>
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<tr>
<td>MCR</td>
<td>Maximum continuous rating</td>
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<tr>
<td>MFB</td>
<td>Mass fraction burned</td>
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<tr>
<td>MLP</td>
<td>Multi-layer perception</td>
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<td>MPa</td>
<td>Megapascal</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>MRE</td>
<td>Mean relative error</td>
</tr>
<tr>
<td>MSE</td>
<td>Mean square error</td>
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<tr>
<td>NBP</td>
<td>National Biofuel Policy</td>
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<tr>
<td>NDIR</td>
<td>Non-dispersive infrared</td>
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<tr>
<td>NO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>Nitrogen oxides</td>
</tr>
<tr>
<td>PFAD</td>
<td>Palm fatty acid distillate</td>
</tr>
<tr>
<td>PFAME</td>
<td>Palm fatty acid methyl ester</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
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<tr>
<td>rpm</td>
<td>Revolutions per minute</td>
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<tr>
<td>RoHR</td>
<td>Rate of heat release</td>
</tr>
<tr>
<td>RoPR</td>
<td>Rate of pressure rise</td>
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<tr>
<td>SOC</td>
<td>Start of combustion</td>
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<tr>
<td>SOI</td>
<td>Start of injection</td>
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<tr>
<td>SO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>Sulphur oxides</td>
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<td>TDC</td>
<td>Top dead centre</td>
</tr>
<tr>
<td>ULSD</td>
<td>Ultra-low sulphur diesel</td>
</tr>
<tr>
<td>VDC</td>
<td>Voltage direct current</td>
</tr>
<tr>
<td>WPS</td>
<td>Wavelet power spectrum</td>
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REFERENCES


