

THE EFFECTS OF FUSEL OIL WATER
CONTENT REDUCTION ON PERFORMANCE
AND EMISSIONS OF SI ENGINE WITH FUSEL
OIL –GASOLINE BLENDED FUEL

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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

Keselamatan tenaga dan pemanasan global adalah dua daya penggerak utama bagi pembangunan alkohol dunia yang juga salah satu usaha untuk membangunkan industri pertanian. Secara amnya, bahan api alkohol dihasilkan dari beberapa sumber dan mempunyai nilai pemanasan yang rendah berbanding bahan bakar fosil. Nilai oktana penyelidikan dan nilai oktana motor yang tinggi kandungan oksigen yang tinggi (30.23% wt) dan titik mendidih tunggal minyak fusel telah menunjukkan bahawa ia boleh digunakan sebagai bahan bakar dalam enjin SI. Sebaliknya, kandungan air yang lebih tinggi dalam minyak fusel iaitu sekitar (10-20%) menghasilkan nilai pemanasan minyak fusel yang lebih kecil sebanyak 31% berbanding petrol. Kandungan air yang lebih tinggi dalam minyak fusel memberi kesan negatif terhadap kecekapan pembakaran, oleh kerana itu prestasi enjin dan pelepasan akan terjejas. Analisis komprehensif terhadap sifat-sifat, prestasi dan pelepasan daripada minyak fusel telah dilakukan. Data sifat-sifat minyak fusel-petrol dianalisis secara statistik dengan cara yang berbeza untuk menunjukkan kesan sebelum dan selepas pengekstrakan air daripada minyak fusel terhadap sifat-sifat bahan api yang diuji. Ujikaji yang dijalankan keatas enjin SI suntikan langsung dijalankan dengan menggunakan campuran minyak fusel-petrol dan petrol yang asli telah digunakan sebagai bahan api asas pada kedudukan injap pendikit terbuka yang berbeza (% WOT) sebagai beban enjin dan kelajuan enjin (rpm). Metodologi tindakbalas permukaan (RSM) berasaskan penyesuaian pelbagai objektif telah digunakan dalam kajian ini untuk menentukan nisbah campuran optimum minyak fusel sebelum dan selepas pengekstrakan air (FBWE10, FBWE20, FAWE10, dan FAWE20) terhadap prestasi dan pelepasan. Nilai pemanasan dan kandungan karbon dalam minyak fusel memberi kesan positif yang ketara selepas pengekstrakan kandungan air sebanyak 13% dan 7%, sementara itu kandungan oksigen telah berkurang. Menurut analisis statistik daripada hasil ujian sifat bahan api (campuran fusel minyak-petrol), nilai pemanasan, kandungan oksigen, dan kandungan karbon mempunyai kesan ketara secara statistik terhadap ujian bahan api setelah pecahan minyak fusel meningkat terutamanya selepas pengekstrakan kandungan air. Kuasa enjin telah bertambah baik dengan pengekstrakan kandungan air dan kuasa brek tertinggi telah dicapai FAWE10 di bawah bahan bakar kaya ($\lambda < 1$). BSFC yang terendah dilaporkan adalah 275 g / kW.h pada petrol manakala BSFC tertinggi adalah FBWE10 yang dilaporkan pada 285 g / kW.h. Selain itu, BSFC telah menurun secara purata sebanyak 6.8% dan 1.7% yang mana dibandingkan masing-masing antara FAWE10 dan FBWE0, FAWE20 dan FBWE20. Kandungan air dalam minyak fusel menyebabkan pengurangan dalam pembakaran enjin menyebabkan pembebasan NO_x berkurang. Bahan api campuran mempunyai kesan yang tidak ketara terhadap kuasa brek sementara kesan bahan api campuran yang paling ketara adalah pada tindak BTE dan BSFC. Kandungan air yang diekstrak dari minyak fusel (FAWE10 dan FAWE20) mempunyai kepentingan statistik untuk meningkatkan BTE, pelepasan NO_x dan mengurangkan BSFC dan pelepasan hydrocarbon (HC) dan tidak memberi kesan yang ketara terhadap kuasa brek. Oleh itu, penyelesaian terbaik adalah dengan 20% campuran minyak fusel selepas air diekstrak (FAWE20) pada beban dan kelajuan enjin yang lebih tinggi. Akhir sekali, hasil daripada ujian pengesahan menunjukkan persetujuan yang baik dengan data ujikaji dan peratusan maksimum ralat adalah kurang daripada 5%. Penemuan kajian ini akan memberi sumbangan besar kepada penggunaan masa hadapan bahan api fusel dalam enjin pembakaran dalaman dengan meningkatkan nilai pemanasan

ABSTRACT

Energy security and global warming concerns are the two main driving forces for the global alcohol development that also has the effort to animate the agro-industry. Generally, alcohol fuels are produced from several sources and have less heating value than fossil fuel. Fusel oil is a by-product obtained through the fermentation of some agricultural products such as beets, cones, grains, potatoes, sweet potatoes, rice and wheat. The high research octane number and motor octane number (RON 106 and MON 103), high oxygen content (30.23% wt) and single boiling point of fusel oil indicated it can be used as a fuel in SI engines. On the other hand, the higher water content of fusel oil (around 10-20%) led to a lower heating value by 31% compared to gasoline. Also, the higher water content of fusel oil effect negatively on the combustion duration, thereby engine performance and emission are affected. Comprehensive analyses of the fusel oil properties, performance and emissions have been performed. The data of fusel oil-gasoline properties were analyzed statistically in different ways to indicate the effects of fusel oil before and after water content extraction on the test fuels properties. The experimental conducted with direct injection SI engine run with fusel oil-gasoline blends and pure gasoline as the baseline fuel at different open throttle valve positions (% of WOT) as engine loads and engine speeds (rpm). Response surface methodology (RSM) based multi-objective optimization was applied in this work to determine the optimal blend ratio of fusel oil –gasoline before and after water extraction (FBWE10, FBWE20, FAWE10, and FAWE20) on the performance and emissions. The heating value and carbon content of fusel oil improved significantly after extracting the water content by 13% and 7%, respectively, while the oxygen content reduced. According to the statistical analysis of test fuel properties results (fusel oil-gasoline blends), the heating value, oxygen, and carbon content have statistically significant effects on the test fuels as the fraction of fusel oil increased especially after water content extraction. The engine power has improved with the extraction of water content and the highest brake power is registered with FAWE10 under rich fuel ($\lambda < 1$). The lowest brake specific fuel consumption (BSFC) is reported to be 275 g/kW.h with gasoline while the highest BSFC is with FBWE10 which is reported to be 285 g/kW.h. Furthermore, the BSFC has decreased on average by 6.8% and 1.7% with FAWE10 and FAWE20, compared to FBWE 10 and FAWE20 respectively. The water content of fusel oil led to the limitation of the engine combustion thereby the NO_x emission reduced. The blended fuel has insignificant effects on brake power while the highest impact of blended fuel was on BTE and BSFC responses. The extracted water content from fusel oil (FAWE10 and FAWE20) has a statistical significance in order to increase the brake thermal efficiency (BTE), NO_x emission and decrease the brake specific fuel consumption (BSFC) and HC emissions while having insignificant effects on brake power. Thus, the best solution was with 20% of fusel oil after water extraction (FAWE20) at higher load and engine speed. Finally, the validation of the results showed a good agreement with the experimental data and the maximum percentage of error which is less than 5%. The findings from this study will make significant contributions to the future applications of fusel fuel in an internal combustion engine by improving the heating value.

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LIST OF SYMBOLS

| | |
|-----------|--|
| k | Ratio of specific heat |
| θ | Crank angle (degree) |
| μ | Dynamic viscosity (cp) |
| BP | Brake power (kW) |
| C | Carbon content (%) |
| H | Hydrogen content (%) |
| mf | Fuel mass flow rate (g/hr) |
| N | Nitrogen content (%) |
| N | Engine speed (rpm) |
| NC | Number of cycles |
| O | Oxygen content (%) |
| p | Cylinder pressure (bar) |
| S | Sulphur content (%) |
| T | Torque (N.m) |
| V | Cylinder volume (cm ³) |
| λ | Relative fuel-air ratio |
| v | Kinematic viscosity (mm ² /s) |
| ρ | Density (kg/m ³) |

LIST OF ABBREVIATIONS

| | |
|-----------------|---|
| AK | Anti-knocking |
| ANOVA | Analysis of variance |
| ASTM | American society of testing materials |
| ATDC | After top dead centre |
| BMEP | Brake mean effect pressure |
| BP | Brake power |
| BSFC | Brake specific fuel consumption |
| BTDC | Before top dead centre |
| BTE | Brake thermal efficiency |
| Btu | British thermal unit |
| CAD | Crank angle degree |
| CD | Combustion duration |
| CE | Combustion efficiency |
| CFR | Cooperative fuels research |
| CN | Cetane number |
| CO | Carbon monoxide |
| CO ₂ | Carbon dioxide |
| COI | Cone of influence |
| COV | Coefficient of variation |
| CR | Compression ratio |
| CS | Combustion speed, |
| CT | Cylinder temperature |
| CWT | Continuous wavelet transforms |
| DF | Degree of freedom |
| DI | Direct injection |
| DISI | Direct injection spark ignition |
| DME | Dimethyl ether CH ₃ OCH ₃ |
| DMF | Dimethylfuran |
| DoE | Design of Experiment |
| DST | Different Spark timing |
| EGR | Exhaust gas recirculation |
| F0 | 100% Gasoline |
| FAWE | Fusel oil After water extraction by volume |
| FAWE20 | 90% Gasoline + 10% fusel oil after water extraction by volume |

| | |
|--------|--|
| FAWE20 | 80% Gasoline + 20% fusel oil after water extraction |
| FBWE | Fusel oil before water extraction |
| FBWE10 | 90% Gasoline + 10% fusel oil before water extraction |
| FBWE10 | 80% Gasoline + 20% fusel oil before water extraction |
| FS | Flame speed |
| GC-MS | Gas Chromatography–Mass Spectrometry |
| GHG | Greenhouse gases |
| H | Hydrogen |
| HC | Hydrocarbon |
| HCCI | Homogeneous charge compression ignition |
| HHV | Higher heating value |
| HSD | Honest significant difference |
| ICE | Internal combustion engine |
| LHOV | Latent heat of vaporization |
| LHV | Lower heating value |
| LUC | Land-use change |
| MFB | Mass fraction burned |
| MTBE | Methyl tertiary-butyl ether |
| NAP | National alcohol program |
| POAE | Percentage of absolute error |
| PST | Phase Separation Temperature |
| REP | Reid evaporation pressure |
| ROHR | Rate of Heat Release |
| ROPR | rate of pressure rise |
| SFC | Specific fuel consumption |
| SSd | Sum of the squared deviations |
| SSt | Total sum of squared deviations |
| TCD | Thermal conductivity detectors |
| TEL | Tetraethyl lead |

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