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PREDICTING ENGINE PERFORMANCE AND EXHAUST EMISSIONS OF A SPARK IGNITION ENGINE FUELLED WITH 2-BUTANOL-GASOLINE BLENDS USING RSM AND ANN MODELS

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Doctor of Philosophy

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We hereby declare that we have checked this thesis and in our 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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ABSTRAK

Penyelidikan eksperimen dalam pengujian enjin menggunakan bahan bakar alternatif selalunya tertakluk kepada operasi enjin, yang memerlukan masa dan pembiayaan kos bahan yang mahal. Atas sebab-sebab ini, kajian ini bertujuan untuk meramalkan prestasi enjin dan pelepasan ekzos menggunakan 2-butanol-gasoline bahan api yang dicampur dengan nisbah peratusan 5:95 (GBu5), 10:90 (GBu10) dan gasoline 15:85 (GBU-15) kepada 2-butanol, masing-masing, yang dikendalikan dalam empat silinder, empat lejang bahan api 4G93 Mitsubishi pada kedudukan pendikit lebar 30%, 50% dan 70% menggunakan metodologi permukaan tindak balas (RSM) dan rangkaian saraf tiruan (ANN). Berdasarkan eksperimen penyiasatan tersebut, pada 30%, 50% dan 70% daripada kedudukan pendikit lebar, 2-butanol-gasoline bahan api dicampur menunjukkan peningkatan kuasa brek enjin, brek tork dan kecekapan haba brek dengan peningkatkan kandungan 2-butanol dalam bahan api petrol. Prestasi enjin menunjukkan peningkatan dalam kuasa brek, brek tork dan brek thermal kecekapan dalam purata 2% hingga 15% dan 0.2% kepada 1.5%, masing-masing, untuk semua kedudukan pendikit diuji berkenaan dengan meningkatkan kandungan 2-butanol dalam bahan api petrol. Untuk pelepasan ekzos, ianya telah dicatatkan, penurunan yang sekata bagi nitrogen oksida (NO_x), carbon monoksida (CO), carbon dioksida (CO_2) dan hydrocarbon yang tidak terbakar (HC) untuk GBu5, GBu10 dan GBU-15, secara purata sebanyak 7.1%, 13.7%, dan 19.8% daripada G100, masing-masing, lebih jarak kelajuan 1000 hingga 4000 RPM. Kandungan pelepasan lain menunjukkan CO dan HC lebih rendah tetapi CO_2 lebih tinggi dari 2500 hingga 4000 RPM untuk bahan api campuran. Seterusnya, kelajuan enjin, bahan api campuran 2-butanol dan kedudukan pendikit enjin dan hasil dari prestasi enjin dan ekzos ciri-ciri pelepasan telah digunakan sebagai input dan output untuk metodologi RSM dan ANN. Berdasarkan model RSM, ciri-ciri prestasi mendedahkan bahawa kenaikan 2-butanol dalam bahan api yang dicampurkan membawa kepada peningkatan aliran kuasa brek, brek tork dan kecekapan terma brek. Bagaimanapun, bahan api brek didapati sedikit lebih tinggi diperhatikan. Tambahan pula, RSM model ini mencadang bahawa kehadiran 2-butanol mempamerkan trend penurunan kepada NO_x, CO dan HC, bagaimanapun trend yang lebih tinggi dapat diperhatikan untuk pelepasan CO_2 dimana keputusan ini adalah selari dengan keputusan eksperimen. Sementara itu, bagi ANN pula, kedua-dua lapisan tersembunyi model ANN dilatih tansig-logsig gabungan fungsi pengaktifan menghasilkan koefisien korelasi terbaik, R pada nilai 0.9995 terhadap gabungan fungsi pengaktifan lain yang dinilai. Walau bagaimanapun, untuk mencapai model ramalan yang lebih tepat, semua konfigurasi dinilai lebih lanjut oleh tambahan analisis kesilapan statistik dan korelasi metrik, iaitu Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Theil U2, Nash-Sutcliffe Efficiency (NSE) and Kling–Gupta Efficiency (KGE). Penilaian, gabungan fungsi pengaktifan terbaik untuk kuasa brek, BSFC, BTE, NOx, CO, dan model ANN bagi CO_2 adalah konfigurasi tansig-logsig. Bagi tork Brek dan HC, kombinasi tansig memberikan ramalan yang lebih baik. Ia boleh ditunjukkan dengan tepat daripada kajian bahawa model ANN yang maju mempunyai ketepatan ramalan yang lebih tinggi berbanding dengan model RSM.

ABSTRACT

Experimental investigation in engine testing using alternative fuels always subjected to more engine operation, time-consuming and require expensive cost of materials. For these reasons, this study is aimed to predict the engine performance and exhaust emissions using 2-butanol-gasoline blended fuels with percentage volume ratios of 5:95 (GBu5), 10:90 (GBu10) and 15:85 (GBu15) of gasoline to 2-butanol, respectively, operated in a four-cylinder, four-stroke port fuel 4G93 Mitsubishi spark ignition engine at 30%, 50% and 70% of throttle position using artificial neural network and response surface methodology techniques. Based on the experimental investigation, at 30%, 50% and 70% of throttle position, 2-butanol–gasoline blended fuels indicated an improvement in engine brake power, brake torque and brake thermal efficiency with increasing 2-butanol content in the gasoline fuels. The engine performance indicated improvement in brake power, brake torque and brake thermal efficiency in the average of 2 to 15% and 0.2% to 1.5%,respectively, for all of the tested throttle position with respect to increasing the 2-butanol content in the gasoline fuel. For exhaust emissions, it was recorded that, a significant decreased of NO_x, CO, CO_2 and HC for GBu5, GBu10 and GBu15, by an average of 7.1%, 13.7%, and 19.8% than G100, respectively, over a speed range of 1000 to 4000 RPM. Other emission contents indicate lower CO and HC but higher CO_2 from 2500 to 4000 RPM for the blended fuels. The engine speeds, 2-butanol blended fuels and engine throttle position and results from the engine performance and exhaust emissions characteristics was then used as the input and output for the for the artificial neural network and response surface methodology. Based on the RSM model, performance characteristics revealed that the increment of 2-butanol in the blended fuels lead to the increasing trends of brake power, brake torque and brake thermal efficiency. Nonetheless, a marginally higher brake specific fuel consumption was observed. Furthermore, the RSM model suggests that the presence of 2-butanol exhibits a decreasing trend of NO_x, CO, and HC, however, a higher trend was observed for CO_2 exhaust emissions, which are in accordance with the experimental results. Meanwhile, for ANN it was shown that the two hidden layer ANN model trained with the tansig-logsig activation function combination yields the best correlation coefficient, R at a value of 0.9995 against other activation function combinations evaluated. However, to attain a higher fidelity prediction model, all the configurations are further assessed by additional statistical error and correlation metrics, namely Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Theil U2, Nash-Sutcliffe Efficiency (NSE) and Kling–Gupta Efficiency (KGE). Following the evaluation, the best activation function combination for the brake power, BSFC, BTE, NO_x, CO, and CO_2 ANN predictive models is the tansig-logsig configuration. As for Brake torque and HC, the tansig combination provides a better prediction. It can be conclusively shown from the study that the developed ANN models have a higher predictive accuracy as compared to the RSM model.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Abbreviations

°CA	degree of crank angle
AP_e	average effective pressure
$CH_3CH_2CH_2CH_2OH$	n-butanol
$CH_3CH_2CHOHCH_3$	2-butanol
$C_nH_{2n+1}OH$	alcohol structure formula
CH_3OH	methanol structure formula
C_2H_5OH	ethanol
C_3H_7OH	propanol
C_4H_9OH	butanol
$(CH_3)_2CH_2CHOH$	iso-butanol
$(CH_3)_3COH$	tert-butanol
P_e	effective power
P_{max}	maximum pressure
Nm	newton metre
R	correlation coefficient
R^2	coefficient of determination
Te_x	exhaust gas temperature
rpm	revolutions per minute
-OH	hydroxyl group

LIST OF ABBREVIATIONS

Abbreviations

AFR	air fuel-ratio
ANN	artificial neural network
AI	artificial intelligence
bTDC	before top dead centre
BDC	bottom dead centre
BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
BVP	butanol Volume Percentage
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
COP21	Conference of the Parties
COV	coefficient of variation
DA	direction accuracy
DLS	damped least-squares
ECI-multi	electronically controlled multi-point fuel injection
EU	european union
FF	feedforward
FIT	fuel injection timing
FIP	fuel injection pressure
G100	Gasoline
GBu5	5% 2-butanol + 95 gasoline
GBu10	10% 2-butanol + 90% gasoline
GBu15	15% 2-butanol + 85% gasoline
GNA	gauss–newton algorithm
GHG	greenhouse gasses
H_nOME	honne oil methyl ester
IMEP	indicated mean effective pressure
HC	unburned hydrocarbon
HCCI	homogenous charge compression ignition engine

KGE	kling–gupta efficiency
LR	linear regression
LHV	lower heating value
Logsig	hyperbolic log-sigmoid
MAPE	mean absolute percentage error
CAD HRRmax	location of heat release rate
CAD P_{max}	location of maximum pressure
CuHRR	cumulative heat release rate
CI	compression ignition
MLP	multilayer perceptron
MSE	mean square error
MSRE	mean square root error
NO_x	nitrogen oxides
PME	peanut methyl ester
ppm	parts per million
purelin	linear function
RBF	radial basis function
RSM	response surface method
RSE	relative standard error
RMSE	root mean square error
rpm	revolutions per minute
SI	spark ignition
SHL	single hidden layer
SOHC	single overhead camshaft
Tansig	hyperbolic tangent sigmoid
TDC	top dead centre
THL	two hidden layer
trainbfg	quasi-Newton backpropagation
trainrp	resilient backpropagation
trainscg	scaled conjugate gradient
traingdx	variable learning rate
UN	united nation
WCO	waste cooking oil
WTO	wide throttle open

NSE	nash–sutcliffe coefficient of efficiency
n-butanol	primary butyl alcohol
2-butanol	secondary butyl alcohol

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