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Simulation of a hydrogen/natural gas engine and modelling of engine operating parameters

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ABSTRACT

At the present work for improving the engine performance and decrease of emissions, a port injection gasoline engine is converted into direct injection. Engine performance behavior was investigated by AVL Fire software with adding hydrogen to natural gas from 0% up to 30%. Validation of the simulated model and experimental results show good confirmation. To determine the relationship between independent variables engine speed, ignition timing, injection timing and H_2% versus the dependent variables including engine performance parameters, specific fuel consumption, CO and statistical analysis models were used. Comparison between different errors models shows that Radial basis function model with training algorithm Bayesian regularization back propagation can estimate better engine performance variables. The results showed that adding hydrogen to natural gas cause the output power, torque, fuel consumption efficiency increase and specific fuel consumption drop. Also, CO decreases when ignition and injection timing be advanced and engine speed reaches to its largest.

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Introduction

Growing concerns on the harmful effects of conventional fossil fuel emissions have made natural gas (NG) a very attractive alternative fuel for internal combustion engines (ICEs), particularly for its advantages, which include being environment friendly, clean burning, economical and efficient [1]. Also, hydrogen offers high flame speeds, a wide flammability range [2–4], low minimum ignition energy and no emissions of HC or CO_2 [5,6]. Rising the engine performance and reducing exhaust emissions and use of non-fossil fuels Instead of fossil fuels is the main scope of today vehicles. Accessibility and numerous advantages of natural gas are the main factors for motor manufacturing companies to move towards transporting vehicles that use natural gas instead of gasoline fuel [7,8]. Adding hydrogen to natural gas is more effective on improving the performance of spark-ignition engines and the combustion characteristics of HCNG engines are strongly dependent on the conditions of the engine [9]. Also, hydrogen enrichment could increase flame speed and promote the engine power and decrease the exhaust pollution so that adding H2 in the blend reduces the specific fuel consumption and increases the thermal efficiency [10–12]. Zhang et al. studied the effect of different ignition timing on combustion and emissions characteristics in an engine with enriched hydrogen in the blend [13]. The results showed that mean effective pressure first started to decrease and then slightly increased as the ignition timing proceeded; also, HC and CO emissions were decreased when hydrogen was added.

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Nomenclature

ANN	Artificial neural network
ANOVA	Analysis of variance
2FI	Interaction factor
aBDC	Intake valve closing
bBDC	Exhaust valve opening
aTDC	Exhaust valve closing
bTDC	Intake valve opening
BSFC	Brake-specific fuel consumption
BTDC	Before top dead center
CA	Crank angle degree
CFD	Computational fluid dynamics
CI	Compression-ignition
CNGDI	Compressed natural gas with direct injection system
CO	Carbon monoxide
CO_2	Carbon dioxide
EF	Efficiency model
ES	Engine speed
$H_2\%$	Volume fraction of hydrogen
HC	Hydrocarbon
HCNG	Mixture of hydrogen and natural gas
ICE	Internal combustion engine
IGT	Ignition timing
IT	Injection timing
LHV	Lower heating value
MAPE	Mean absolute percentage error
MLP	Multi-layer perceptron
MLR	Multiple linear regression
MSE	Mean square error
NG	Natural gas
NOx	Nitrogen oxide
O_2	Oxygen
R^2	Coefficient of determination
RBF	Radial basis function
RMSE	Root mean square error
SCRE	Single cylinder research engine
SFC	Specific fuel consumption
SI	Spark ignition
T	Temperature
WOT	Wide open throttle position
trainbr	Bayesian regularization backpropagation
trainlm	Levenberg-Marquardt backpropagation

Effect of injection timing on performance and exhaust emissions of a diesel engine using diesel–methanol blends at different speeds showed that CO decreased and NOx and CO2 emission increased as did brake specific fuel consumption and brake thermal efficiency for injection timing of 15°, 20° and 25° before top dead center (BTDC) [14–16]. In an experimental work, as injection timing was advanced, CO and unburned HC emissions were decreased while NOx and CO emissions increased. When the injection timing was advanced, CO emission was decreased because of the improved reaction between fuel and oxygen [14,16,17]. Natural gas (NG) has been extensively investigated for the use in spark-ignition (SI) and compression-ignition (CI) engines [18]. The effect of increasing hydrogen to natural gas having a high compression ratio on the performance and emissions of a spark ignition engine and The experimental results showed that the maximum power was obtained with HCNG5% [19] and adding Hydrogen to CNG enhanced combustion rate and extended the lean misfire limit [20]. A great improvement was provided with hydrogen addition to diesel fuel and the increase in peak heat release rate with 20% hydrogen [21]. With hydrogen volume fraction increasing and different ignition timing from 4 to 16° BTDC in a hydrogen direct injection stratified gasoline engine showed that CO and HC emissions dropped and NOx emission rose [22,23]. Post-injection can reduce unburned hydrocarbon and engine can be driven by the difference in pressure and temperature condition during and after the post -injection [24].

In the recent decades, artificial neural networks have been widely used to estimate engine parameters and many fields of automotive engineering [25]. Artificial neural networks (ANNs) operate like neural networks of the human brain. In facts, the non-linear and hidden relationships between variables were obtained through trial and error. So, many successful studies in estimating engine operating parameters are done by ANN and artificial neural network (ANN) to demonstrate its efficiency and viability [26–28]. Haghighi et al. used MLP neural network for the prediction of engine operating parameters including engine power, soot, NOx, CO_2, O_2 and temperature versus excess air percent, engine speed, torque, and fuel mass [29]. Zweiri & Seneviratne used ANN model to estimate single-cylinder diesel engine whose results confirmed the ability of ANN [30]. Kiani et al. estimated the engine thermal balance in the spark ignition engine with a minimum 0.99 R^2 by ANN [31]. Jahirul et al. showed that the minimum R^2 between actual and practical value is 0.96 when ANN is used to estimate engine brake power, brake-specific fuel consumption, and engine efficiency in CNG engines [32]. And, the least R^2 value of ANN model was 98% to estimate brake-specific fuel consumption, brake thermal efficiency, exhaust gas temperature, and exhaust emissions of the engine [33]. Toghyani et al. estimated the power and torque for stirling engine heat with the aid of neural network with $R^2 > 0.9$ and used multiobjective optimization rather than starting point by trial and error into a single criterion [34]. Sarala et al. could obtain good results using ANN-MLP in the estimation of the exhaust emissions of a single-cylinder, four-stroke diesel engine [35]. Parlak et al. modeled specific fuel consumption and exhaust temperature in a diesel engine and also Ghobadian et al. modeled torque, BSFC, HC and CO parameters versus engine speed and percent of bio-fuel blend [36,37]. Zhen-Tao and Shao-mei also used RBF neural network model to estimate the emission variable of the CNG-diesel engine including CO and NOx according to rotation speed, the quantity of natural gas, and injection timing [38]. Yusaf et al. estimated the parameters of brake power torque, BSFC, BTE, NOx, CO, CO_2, O_2 and T exhaust versus engine speed and dual fuel engine (CNG-diesel) using RBF neural network model [39]. There are many other studies that show artificial neural network can successfully predict many parameters of engine performance [39–42].

The purpose of this paper is to simulate the behavior of SI engine by using CFD to study the use of hydrogen as a fuel additive in CNG engine. As well, using CFD model results,

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