PERFORMANCE PREDICTION OF A CI ENGINE USING ARTIFICIAL NEURAL NETWORK FOR VARIOUS SME AND DIESEL FUEL BLENDS

Burak GOKALP
Kocaeli University
burakgokalp@hotmail.com

H. Ibrahim SARAC
Kocaeli University

H. Metin ERTUNC
Kocaeli University

Murat HOSOZ
Kocaeli University

H. Serhad SOYHAN
Sakarya University

Abstract

This study deals with predicting various performance parameters and exhaust emissions of a four-stroke, four-cylinder, direct injection diesel engine fuelled with soybean oil methyl ester (SME) and its 5%, 20% and 50% blends with jet fuel, marine fuel and No.2 diesel fuel using artificial neural networks (ANNs). In order to acquire data for training and testing the proposed ANN, the test engine was operated at steady-state conditions while varying the engine speed and torque for each fuel case. Using some of the experimental data for training, an ANN model based on standard back propagation algorithm for the engine was developed. This model was used to predict various performance parameters and exhaust emissions of the engine, namely the brake specific fuel consumption, break thermal efficiency, mechanical efficiency, exhaust gas temperature, and emissions of CO, NO_x, and CO_2. Then, the performance of the ANN predictions were measured by comparing the predictions with the experimental results. It was observed that the ANN model can predict the engine performance and exhaust emissions quite well with correlation coefficients in the range of 0.937ï 0.989%, mean relative errors in the range of 0.36ï 16.72% and very low root mean square errors. The results reveal that the ANN approach can accurately predict the performance and emissions of diesel engines using various diesel and biodiesel fuels.

Keywords: *Marine fuel, Jet fuel, Soybean oil methyl ester, ANN, Performance prediction*

1. Introduction

Since the advent of the diesel engine over a century ago, many research studies have been conducted to improve the engine performance, decrease the engine fuel consumption and reduce the unwanted exhaust emissions. The oil crisis of the 1970s accelerated the interest of using alternative fuels for diesel engines although diesel fuel has remained as the main fuel. Among these alternatives, the alkyl monoesters of fatty acids from vegetable oils, also named as biodiesels, have received an increasing attention in the past decade. Because biodiesel is a biodegradable and non-toxic alternative fuel with properties very close to diesel fuel, diesel engines can be fuelled with biodiesel without needing a modification. Biodiesels have a higher cetane number, no aromatics, no sulphur and contains 10ï 11% oxygen by weight. Therefore, the exhaust emissions of a diesel engine fuelled with biodiesel contain less carbon monoxide, hydrocarbon and particulate matter compared to diesel fuel. However, the oxygen content of biodiesel lowers its energy content and increases fuel consumption [1]. The performance and exhaust emissions of diesel engines using various biodiesels have been studied by many investigators [2ï 8]. Kalligeros *et al.* [9] investigated the performance of a diesel engine using the blends of biodiesel and traditional marine diesel fuel. Arkoudeas *et al.* [10] studied the performance of a compression ignition engine fuelled with blends of JP-8 (jet fuel) and biodiesel. The performance and exhaust emissions of a diesel engine using various fuels for the entire range of operating conditions can be determined by conducting a comprehensive experimental study. However, testing the engine under the all possible operating conditions and fuel cases are both time consuming and expensive. Alternatively, the performance and exhaust emissions of an engine can be modelled using ANNs, which allow the modelling of complex physical phenomena without requiring explicit mathematical representations. However, this new modelling technique can be applied to predict the output parameters of the considered system as long as enough experimental data for training is provided. The ANN technique has been used for modelling the performance of various thermal systems [11ï 17]. Recently, ANNs have been applied to estimate various performance parameters of internal combustion engines. This approach was used to predict the performance and exhaust emissions of diesel engines [18ï 20] and a gasoline engine [21].

In this study, the application of an ANN for predicting the performance and exhaust emissions of a diesel engine using soybean oil methyl ester (SME), various diesel fuels and their blends has been investigated. The experimental data from totally 52 test runs was utilized to train and test the ANN model for predicting the brake specific fuel consumption, break thermal efficiency, mechanical efficiency and exhaust gas temperature of the engine together with the exhaust emissions of CO, CO_2 and NO_x.

2. Experimental setup and testing procedure

The experiments were performed on a four-cylinder four-stroke direct injection TZDK Basak diesel engine, which was originally designed for No.2 diesel fuel. The schematic layout of the experimental apparatus is shown in Fig. 1. The engine has a maximum power output of 40 kW, a compression ratio of 16.8:1, a cylinder bore of 100 mm, a stroke of 100 mm, and a displacement of 3140 cm^3. The engine was coupled to a Schenk eddy current hydraulic dynamometer, and the engine speed was measured with a tacho-generator connected to the dynamometer. The load and speed of the engine were controlled by adjusting the dynamometer resistance and injection rate of the fuel pump. The fuel consumption of the engine was determined by measuring the fuel level decrease in a measurement container in a given period of time. The volumetric flow rate of the intake air was measured using a rotary type flow meter. A surge tank located between the air flow meter and intake manifold was used for damping out the pulsations produced by the engine, thus obtaining a steady air flow. The exhaust gas temperature was measured using a thermocouple connected to the exhaust pipe just downstream of the exhaust manifold. The cooling water temperatures at the inlet and outlet of the engine block were measured using Pt100 thermocouples. The exhaust emissions, namely CO, CO_2 and NO_x, were measured using Horiba gas analyser. Initially, the engine was tested with the pure fuels of No.2 diesel fuel (D2), jet fuel (JF), marine fuel (MF) and soybean oil methyl ester (SME). Then, 5%, 20% and 50% blends of SME with D2, JF and MF were also tested. Physical characteristics of the tested fuels are given in Table I. All tests were performed under steady-state conditions. The brake specific fuel consumption (*BSFC*), brake thermal efficiency (*BTE*), mechanical efficiency (*ME*), exhaust gas temperature, and exhaust emissions such as CO, CO_2 and NO_x have been investigated.In the tests, the engine speed was changed between 1200 and 2400 rpm with intervals of 400 rpm, while the engine was operated at full load. At these conditions, the produced torque changed between 164.2 Nm (at 2400 rpm) and 200.4 Nm (at 1200 rpm). Before each fuel test, the fuel tank of 16000 cm^3 capacity and fuel lines were drained, filled with the new fuel, and the engine was operated at least 15 minutes to stabilize on the new fuel. At each speed, the engine was operated five minutes to achieve steady-state conditions, and the data were collected at the sixth minute. Each test was repeated 3 times and the results of the three repetitions were averaged. In each test, coolant and exhaust temperatures, fuel consumption, airflow rate, and exhaust emissions were recorded systematically. The fuel delivery angle of the traditional fuel injection system was kept constant at 14d BTDC.

3. Modelling with the ANN

The architecture of the ANN for the diesel engine with the names of input and output parameters is schematically illustrated in Fig. 9. The input layer has three neurons corresponding to the three input parameters: engine speed (n), engine torque (T) and the lower heating value (*LHV*) of the tested fuel. The output layer consists of seven neurons, representing the brake specific fuel consumption (*BSFC*), brake thermal efficiency (*BTE*), mechanical efficiency (*ME*), exhaust temperature (T_{exh}), and emissions of NO_x, CO and CO_2. The performance of an ANN model is noticeably affected by the number of hidden layers and the number of nodes in each hidden layer. By trial and error with different ANN configurations, the optimal number of hidden layers and that of neurons in the hidden layer were selected as one and five, respectively. The activation function in the hidden and output layers was chosen as hyperbolic tangent sigmoid function. As a result, a three-layer feed forward ANN is proposed for the prediction of the seven output parameters of the test engine. In order to develop an ANN model for the diesel engine, experimental data was divided into training and test sets. While 70% of the data set was randomly assigned as the training set, the remaining 30% was employed for testing the performance of the ANN predictions. The input vectors with three variables and their corresponding target vectors with seven variables in the training set were presented to the network for training it in three separate groups. The first group contained the test results of pure SME, pure MF and their blends, while the second group consisted of the results of pure SME, pure JF and their blends. Finally, the third group contained the results of pure SME, pure D2 and their blends. The training set of each group consisted of 14 input-output pairs, corresponding to 70% of the data set containing the results of 20 tests in each group. Using Levenberg-Marquardt algorithm [23], which is a popular back propagation algorithm employed in engineering applications, the training procedure adjusted the weighting coefficients and biases so that the output response to the input vector was as close as possible to the desired response (target). The output response was compared to the desired response at each presentation, and an error was computed. This error was then fed back (back propagated) to the network and used for adjusting the weights by a gradient descent method such that the error decreases with each iteration. The training process was terminated when the maximum number of epochs was exceeded or the performance goal was met. Finally, the input vectors from the test data set were presented to the trained network and the network predictions were compared with the experimental outputs for the performance measurement. The test data set contained 6 input-output pairs for each group, corresponding to the 30% of the data set containing the results of 20 tests in each group. Thus, totally 18 prediction points were obtained for each output parameter of the engine. The statistical performance indicators used for measuring the performance of the ANN predictions are the correlation coefficient, mean relative error, root mean square error and absolute fraction of variance. The definitions of these indicators can be found in [14ï 17]. The computer code for training the ANN and measuring its performance was implemented under MATLAB environment [24].

4. Conclusions

The applicability of ANN approach for modelling the performance of a diesel engine using various diesel fuels, a biodiesel and their blends has been studied. Employing the experimental data acquired from steady state operations of an experimental diesel engine, a three layer ANN based on back propagation algorithm was developed. The network was used for predicting performance parameters of the engine, namely *BSFC*, *BTE*, *ME*, exhaust temperature and emissions of CO, CO_2 and NO_x. The ANN model usually resulted in a good statistical performance with the correlation coefficients in the range of 0.937ï 0.989, mean relative errors in the range of 0.36ï 16.72% and very low root mean square errors. Comparisons of the ANN predictions and the experimental results demonstrate that diesel engines using diesel and biodiesel fuels can accurately be modelled using ANNs. Thus, instead of a comprehensive experimental study, the performance and exhaust emissions of diesel engines can easily be determined by performing only a limited number of tests to acquire data for training the ANN, which saves a great deal of engineering effort.