Recent Advances in Mechanical Engineering
Select Proceedings of ICRAME 2020
Lecture Notes in Mechanical Engineering

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The First International Conference on Recent Advancement of Mechanical Engineering (ICRAME 2020) was held from 7 to 9 February 2020 at National Institute of Technology Silchar, Assam, India. The conference aimed to bring together experts from academic, scientific and industrial communities to address new challenges and present their latest research findings, ideas, developments and perspective of the future directions in the field of mechanical engineering. ICRAME 2020 invited researchers to participate in the conference. In this conference, ideas were discussed across the borders among the delegates. Participations of this conference were from all the neighbouring states of the Northeast India and also from other parts of India as well as abroad. There were different topics of interest considered in ICRAME 2020. These were related but not restricted to the following broad areas of mechanical engineering—thermal engineering, design engineering, manufacturing/production engineering and surface engineering. The recent developments in these areas were dealt with in this conference. The conference invited technical papers that addressed the state of the art in the mentioned areas of mechanical science and technology. The papers related to the theoretical modelling works, and analytical and numerical modelling including CFD, experimental investigations and also the state-of-the-art review papers in the relevant areas were considered in ICRAME 2020. The book proceedings publishes all the accepted and presented papers in the said conference. The following are the broad topics of the conference:

- **Thermal Engineering**: Bio-thermal, techniques in fluid flow, compressible flows, biofuels, advancement in renewable energy sources, solar thermal, renewable energy, off-grid renewable energy.
- **Design Engineering**: Computing in applied mechanics and product design, dynamics and control of structures/systems, fracture and failure mechanics, solid mechanics, differential/dynamical systems, modelling and simulation artificial intelligence: fuzzy logic, neural network, etc. Finite element analysis, advanced numerical techniques, advancements in tribology nanomechanics and MEMS, robotics.
• Manufacturing/Production Engineering and Surface Engineering: Casting, welding, etc. Intelligent and advanced manufacturing system, composites, conventional and non-conventional machining, ergonomics: human factors in seating comfort.

Silchar, India K. M. Pandey
Silchar, India R. D. Misra
Silchar, India P. K. Patowari
Guwahati, India U. S. Dixit
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About the Editors

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AI-Based ANN Modeling of Performance–Emission Profiles of CRDI Engine under Diesel-Karanja Strategies

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Abstract The current investigation highlights the impact of Diesel–biodiesel blends on performance and exhaust emission profiles of a single-cylinder, common rail direct injection (CRDI) engine. Experiments were performed at constant engine speed (1500 rpm) and three engine loads (50, 75 and 100%) under high fuel injection pressure (900 bar) with volume proportions (10, 20 and 30%) of Karanja with Diesel. Utilizing CRDI engine experimental data, an artificial intelligence (AI)-affiliated artificial neural network (ANN) model has been created with the intention of forecasting brake thermal efficiency, oxides of nitrogen, unburned hydrocarbon and carbon monoxide emissions. From various tested ANN models, one hidden layer with three neurons along with logsig transfer function has been noticed to be optimum network for Diesel-Karanja paradigms under high fuel injection pressure. While developing the optimum model, standard Levenberg–Marquardt training algorithm has been employed. The optimum ANN model is capable to estimate the CRDI engine performance–emission profiles with an overall correlation coefficient value of 0.99742, wherein 0.99783, 0.99951 and 0.99969 for training, validation and testing datasets, respectively. Results made clear that the formulated AI-based ANN model is viable for predicting the existing CRDI engine performance and emission profiles of Diesel-Karanja blends operating under high fuel injection pressure.
Keywords AI · ANN · CRDI engine · Performance–emission prediction

1 Introduction

The global energy demand in transportation sector has immensely relied on fossil fuels [1]. Fast reduction of petro-fuels and their deleterious effect on environment are creating huge concern over usage of fossil Diesel in conventional Diesel engines. However, Diesel engines are acknowledged for their operational reliability, higher thermal efficiency and lower carbon monoxide (CO) and unburned hydrocarbon (UBHC) emissions [2]. Despite these benefits, stringent emission mandates and limited fossil Diesel reserves may scotch the production and employability of conventional Diesel engine in coming years. Accordingly, most of the research is now intended toward finding an alternative renewable fuel source with acceptable performance and emission characteristics. Research studies [3–6] show that biodiesel has great potential to meet future global energy demand.

The properties of biodiesel primarily depend on the feedstock and processing technology, but usually it has ~11% (by mass) fuel-bound oxygen, high cetane number and low aromatic content when compared to fossil Diesel [5]. Biodiesel also exhibits high flash point temperature which is beneficial for safe storability and transportation [4]. However, the problematic issues of biodiesel are high viscosity and density which result in inferior spray characteristics [2]. Many researchers [3–6] have concluded that the usage of biodiesel in CI engines has resulted in approximately higher oxides of nitrogen (NO\textsubscript{X}) emissions and decreased particular matter (PM), CO and UBHC emissions. In a study by Lee et al. [7] concurred that biodiesel blends have resulted in lower brake thermal efficiency (BTE) and torque but higher NO\textsubscript{X} emissions than pure Diesel operation.

In order to study the performance–emission profiles of a compression ignition (CI) engine over its entire operational range, arduous experimentation is required. To prevail over this problem, computational models are necessary. In this present study, artificial neural network (ANN) technique has been chosen because of its ability to learn, model curvilinear process and flexibility to changes in real time. Yusuf cay [8] developed an ANN model by using feed-forward back propagation method and demonstrated the viability of ANN model in forecasting the performances and exhaust fumes of gasoline engine. In another study Bhowmik et al. [9] devised an ANN model with high accuracy for estimating the indirect injection engine outcomes under ternary blends of Diesel, kerosene and ethanol. Paul et al. [10] discussed the effect of diesel–ethanol pilot fuel on performance–emission characteristics of compression ignition engine operating in dual-fuel mode with compressed natural gas as the main fuel. They created ANN model by using experimental data and stated that the model has good relationship between estimated and experimental values with an overall correlation coefficient ($R$) value of 0.99689. Bhowmik et al. [11] devised an ANN model for predicting output parameters of Diesel engine. The proposed model has given $R$ value which ranges from 0.999312 to 0.999852.
In this study, first experimentation was performed with Diesel-Karanja blends to evaluate performance and emission characteristics. Later, by utilizing this experimental data, an ANN model was formulated by considering the engine load and Karanja biodiesel share in the blend as input parameters and BTE, NOX, UBHC and CO as output parameters.

2 Experimental Setup and Procedure

A single-cylinder, four-stroke, water-cooled, CRDI engine was used for the present investigation. The engine is synchronized to a crank angle sensor for measuring engine rpm. An eddy current dynamometer is synchronized to the CRDI engine for load measurement. By employing, NIRA © -based centralized data acquisition system, each and every instrument fitted to the engine is interfaced to the computer. Gaseous emissions from the CRDI engine are measured by using an AVL MDS 250 and an AVL 437 smoke meter. The engine experiments were performed at three different load conditions, namely 50, 75 and 100% for all the fuel blends (B10, B20 and B30), and high fuel injection pressure of 900 bar is employed for injecting fuels into combustion chamber. During the experimentation, speed of the CRDI engine is kept constant at 1500 rpm. Prior to experimentation, the engine was first run on fossil Diesel fuel at the same operating points to acquire baseline data. To increase the authenticity, the engine experiments were conducted three times, and their mean value has been considered as the final output. Figure 1 encapsulates the schematic of CRDI engine setup.

3 ANN Modeling

ANN is a computational model based on biological processes, predominantly inspired by human brain. Its architecture involves three layers, for instance, input layer, hidden layer and output layer. The experimental data provided to ANN is divided into three sets, namely training dataset, validation dataset and testing dataset [11]. Training dataset is utilized to improve the generalization of the network in predicting the input–output relationship, validation data is used to lessen overfitting of network, and testing data is utilized to validate the generalization capability of model [12]. Complex nonlinear engineering problems can be simulated with the help of neural network tools.
3.1 Selection of Input and Output Parameters

In this study, load and Karanja biodiesel share in the blend are considered as input parameters for predicting the output parameters, namely BTE, NO\textsubscript{X}, UBHC and CO. While developing ANN model, 70\% of the experimental data was defined for training, 15\% of the experimental data was defined for validating, and the rest of the 15\% data was utilized for testing the network.

3.2 Selection of Transfer Function

The transfer function introduces curvilinear transformation into neural architectures so that the model is capable of having nonlinear match between input and output layers [14]. The performance of the neural network is greatly affected by selection of appropriate transfer function. Three basic transfer functions that are available in MATLAB© are logsig, tansig and purlin. Research studies [12–14] concluded that
logsig transfer function is appropriate for predicting the output parameters of a Diesel engine.

### 3.3 Selection of Training Algorithm

In simple, training algorithm is the method followed for updating the connecting weights and bias in order to make improved generalization of input–output relationship. In this study, single hidden layer feed-forward neural network has been used by employing Levenberg–Marquardt back propagation training algorithm (trainlm). Many researchers [15–17] reported that trainlm is fast compared to other training algorithms and it has superior convergence.

### 4 Result and Discussion

Various network topologies were created by changing the number of neurons from two to twenty-five for each of the three basic transfer functions. All the constructed topologies were tested to measure their individual performance. The optimum model has been noticed to occur with logsig transfer function, and the topology comprises of three neurons in its hidden layer, two neurons in its input layer and four neurons in its output layer. Figure 2 shows the overall $R$ value obtained for the optimum model. The overall $R$ value of the optimum ANN model is 0.99742 wherein 0.99783, 0.99951 and 0.99969 for training, validation and testing datasets, respectively.

All the test fuels containing any proportion of biodiesel have shown decreased BTE compared to mineral Diesel operation. This is due to higher viscosity and existence of long chain of unsaturated fatty acid molecules in Diesel–Biodiesel blends compared to mineral Diesel. Among all the test fuels, the D90B10 fuel sample has shown maximum decrease in BTE, which when compared with 50% engine load mineral diesel operating condition it was found to be 15.9% lesser. The developed ANN model has estimated BTE with an $R$ value of 0.998266. Figure 3 shows the comparison of ANN predicted BTE and experimental BTE. Hence, from the value of $R$, it can be inferred that ANN model can be employed for estimating the BTE of CRDI engine energized with Diesel–Biodiesel blends operating with high fuel injection pressure.

$\text{NO}_X$ emissions of Diesel–Karanja blends have been observed to be lower than Diesel fuel. Among all chosen test fuels, the D70B30 fuel sample has shown maximum decrease in $\text{NO}_X$ emissions. It was found that this fuel sample has resulted in 32.3% lesser $\text{NO}_X$ emissions at 50% load condition when compared to pure Diesel. The fabricated ANN model has predicted $\text{NO}_X$ emissions with an $R$ value of 0.9983; from this, we can conclude that the suggested ANN models has proved its viability in approximating the poisonous $\text{NO}_X$ emissions (as shown in Fig. 4). Biodiesel blends has resulted lesser UBHC emission than Diesel fuel. The minimum UBHC emissions among all the test fuels were noticed for D70B30 fuel sample.
When compared to mineral diesel operation, it was found that this fuel sample has shown 56.98% lesser UBHC emission at 100% engine load. The fabricated ANN model has predicted UBHC emission with an $R$ value of 0.9880. The comparison of ANN model mapped UBHC and experimental UBHC is shown in Fig. 5. By comparing the $R$ value of UBHC emission with that of BTE and NOX emissions, it can be deduced that the proposed model has lesser accuracy in estimating the UBHC emission compared to BTE and NOX.

At most experimental conditions, CO emissions resulted from Diesel–biodiesel blends were higher compared to pure Diesel operation. This is due to higher viscosity and existence of long chain unsaturated fatty acid molecules in diesel–biodiesel blends compared to mineral Diesel. The developed optimum model has predicted CO emission with an $R$ value of 0.9810. Figure 6 delineates the comparison of ANN model mapped CO and experimental CO. By comparing the $R$ value of CO emission
Fig. 3 Comparison of experimentally measured BTE with ANN predicted BTE

Fig. 4 Comparison of experimentally measured NO\textsubscript{X} with ANN predicted NO\textsubscript{X}

with that of BTE and NO\textsubscript{X} emissions, it can also be deduced that the proposed model has lesser accuracy in estimating the CO emission compared to BTE and NO\textsubscript{X}. 
Fig. 5 Comparison of experimentally measured UBHC with ANN predicted UBHC

Fig. 6 Comparison of experimentally measured CO with ANN predicted CO

5 Conclusion

The major findings from the experimental cum AI-based ANN model of CRDI engine fueled with various Karanja biodiesel share and engine loads under high fuel injection pressure are as follows:
• At every load condition, Diesel-Karanja blends have shown decreased BTE than Diesel fuel operation.
• NO\textsubscript{X} and UBHC emissions of Diesel-Karanja blends were lower than fossil Diesel at every load condition.
• At most experimental conditions, CO emissions resulted from Diesel-Karanja blends were higher than pure Diesel operation.
• The model developed with logsig transfer function and three neurons in its hidden layer has been noticed to be the optimum model for predicting performance–emission profiles of diesel–biodiesel blends under high fuel injection pressure.
• The optimum model has shown overall $R$ value of 0.99742 wherein 0.99783, 0.99951 and 0.99969 for training, validation and testing datasets, respectively.

ANN has proved its viability in predicting the performance and emission parameters of CRDI engine fueled with Diesel-Karanja biodiesel blends operating under high fuel injection pressure. By utilizing the developed AI-affiliated ANN model, the present investigation can be extended to map the output values at any distinct points of the input parameters under Diesel-Karanja strategies without conducting new experiments which will eliminate the experimental cost, time and effort.

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References

ANFIS Prediction of Performance and Exhaust Emission Characteristics of CRDI Engine Fueled with Diesel–Butanol Strategies

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Abstract The present work investigates the ability of oxygenated Butanol on performance and exhaust emission characteristics of a single-cylinder, four-stroke, water-cooled, common rail direct injection (CRDI) engine. Experiments were performed at constant engine speed (1500 rpm) and six different load conditions, varying from 5 to 30 Nm. Based on CRDI engine experimental data, an artificial intelligence (AI)-affiliated adaptive neuro-fuzzy inference system (ANFIS) model has been formulated for predicting the output parameters, namely brake thermal efficiency (BTE), brake specific energy consumption (BSEC), oxides of nitrogen (NOX), unburned hydrocarbon (UBHC) and carbon monoxide (CO) by considering the engine load and Butanol share in the blend as input parameters. With the increasing Butanol share in the Diesel–Butanol blend, the BTE and BSEC were significantly increased, and exhaust gas emissions, especially NOX and CO, were also reduced. The developed AI-based ANFIS model has the capacity of mapping the relationship between input–output parameters of the CRDI engine with good accuracies. In this study, the statistical performances obtained from ANFIS predicted model are (0.0000107–0.0000755) of mean square error, (0.000353–0.001533) of mean square relative error, (0.999722–0.999939) of correlation coefficient and (0.999444–0.999878) of absolute fraction of variance, which elevated the model capability to a higher stage under Diesel–Butanol strategies.
Keywords Artificial intelligence · ANFIS · CRDI · Performance–emission mapping

1 Introduction

In vehicles like buses, trucks and earth moving machineries, high torque is needed. The higher torque can be produced by the utilization of Diesel engines. Diesel engines have been broadly used to move heavy loads. However, the usage of conventional Diesel fuel in internal combustion engines is one of the major issues for air pollution, due to the high level of exhaust gas emissions, such as particulate matter (PM), oxides of nitrogen (NOX). In recent days, to reduce exhaust gas emissions, from Diesel engines, researchers have shifted toward renewable and eco-friendly sources of alternative energy. Many alternative fuels are available like alcohols, biodiesel, etc. [1]. Among all alternative fuels, alcohols have shown better effects to decrease the emissions from conventional Diesel engines [1]. Alcohols are oxygenated fuel and contain a low amount of sulfur and carbon content as compared to conventional Diesel fuel. Alcohol fuels are restricted for their direct use in Diesel engines because of their poor cetane number [2, 3]. Among various alcohols, the autoignition temperature of Butanol (365 °C) is less than ethanol (479 °C) and methanol (434 °C) [4]. When the blend of Diesel–Butanol is used in the compression ignition (CI) engine, it has high ability to ignite easily. Dogen [5] has concluded that with the increasing proportion of Butanol in Diesel, the performances of the CI engine are significantly improved along with NOX and smoke emissions. Nour et al. [6] investigated that the addition of Butanol share in Diesel, brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) relatively improved alongside NOX, unburned hydrocarbon (UBHC) and carbon monoxide (CO). Compared to other alcohol fuels, Butanol has a higher cetane number and less corrosion and oxygen content. Due to these properties, it is a more suitable additive in CI engine operation than other alcohols [5, 6]. By the process of fermentation of biomass, Butanol can be produced, especially from wastage of plants, corn and algae. Because of its inherent fuel properties and availability, Butanol nowadays is widely used in CI engine operation to partially replace the dependency on conventional Diesel and reduce higher exhaust emissions.

Using the artificial intelligence (AI)-based adaptive neuro-fuzzy inference system (ANFIS) model, the majority of the researchers have developed their model in order to predict the input–output relationship of CI engine [7–9]. Hosoz et al. [10] reported that ANFIS model is a combination of both neural network and fuzzy logic principles. Due to this combination, compared to other artificial intelligence models, this model is able to forecast very efficiently the engine output parameters in a short time. ANFIS also has a great ability to make the fundamental relationship between input and desired output parameters of any sector [11]. Bhowmik et al. [12] surveyed the indirect injection engine outputs for Diesel–Kerosene–Ethanol blends using the ANFIS approach. They reported that the developed model has an overall correlation