ANFIS Model for Prediction of Performance-Emission Paradigm of a DICI Engine Fueled with the Blends of Fish Oil Methyl Ester, n-Pentanol and Diesel

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ABSTRACT

A precise, robust model for complex systems like IC Engines would be much beneficial because of environmental issues, fossil fuel depletion and accumulation of on-road vehicles. The present study depicts the compatibility of higher alcohols like n-pentanol that are produced in renewable ways as a promising blending additive with biodiesel fuels. Biodiesel prepared from the waste parts of the fishes is used to blend with petrodiesel. The methyl esters of fishoil biodiesel (MEFO) and n-pentanol are blended with petrodiesel at different proportions are tested on a four-stroke single cylinder DICI engine and results from witnesses the noble benefits of adding higher alcohols that are observed in both performance and as well as in emissions. The experimental paradigm is further fed to an artificial intelligent model to test the inherent predicting capability an Artificial Intelligent Adaptive Neuro-fuzzy Interface System (ANFIS). A sugeno network with brake power and percentage of biodiesel as input parameters and engine response paradigm such as BSFC, BTE, HC, CO and NOx as outputs are modelled and tested on a statistical platform. It was found that the proposed model is robust and efficient system identification tool to map the input-output response paradigm with high accuracy as the regression (R) values are ranging from 0.9967 to 0.9999, RMSE is ranging 0.000026 to 0.0000336 and MAPE is very low ranging from 0.0021 to 0.0028.

Keywords: *Performance;Emission; ANFIS; Fishoil Biodiesel*

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Introduction

Most significant single wellspring of vitality devoured by the total populace is petroleum, surpassing coal etc. [1]. Oil is an essential part of the creation of composts, plastics and synthetic concoctions. Most specialists expect overall oil excavation will top at some point somewhere in the range of 2007 and 2025, and demand will keep on rising another 40% amid a similar period [2]. The typical 52% ascent in world CO_2 discharges by 2030 and outflows of non-renewable energy sources (counting oil) officially identified with global environmental change [3]. The reliance on limited vitality sources constrained by perilously few, often politically insecure nations, has shockingly prompted a cycle of crisis [4].

Biodiesel, formally known as either methyl-ester or ethyl-ester, is usually happening animal fat or veggie oil which has been scientifically altered to keep running in a compression ignition engine. Biodiesel's leverage contrasted with petrodiesel like its sustainable nature, better discharge, support for household horticulture and compatibility with current running engines without any modifications in engines. Overall biodiesel limit has developed to over 2.2 billion liters because commercial generation started in the early '90s [5]. The US instituted American Society for Testing and Materials (ASTM) D 6751 in the year 2001 which standardizes 14 fuel properties like heating value, cetane index etc. Later, the European Union (EU) in the course of time instituted the biodiesel standard EN 14214 in the year 2003, which antiquated discrete country standards [6].

Extensive research was going in the alternative fuels section from times in these fields and originated some alternatives for petrodiesel that can be used in existing engines without any engine modifications. Biodiesel can be disengaged from vegetable oils as well as animal fats and transesterified with methyl/ethyl alcohols to frame alkyl esters [7]. According to a recent survey, the fish processing industries are discarding the unwanted parts of fishes on a colossal scale consistently around the world. The Central Institute of Fisheries Technology (CIFT) expressed that over one lakh Mg of shrimps are created as fish waste parts annually. As per the International Fishmeal and Fish Oil Organization (IFFO), the world fish oil generation is 1.01 million tons and it will be expanded ten times in next five years [8].

Consequently, fish oil has developed global attention and concern for being a decent reserve of biodiesel for petrodiesel fuel by decreasing the natural poisons and guaranteeing energy security. A few analysts investigated the execution and emission qualities of fish oil biodiesel. The test outcomes demonstrated that the engines worked efficiently with overall efficiency and decrease in emission discharges [9]. CO and CO_2 emissions are considerably lowered with the blends of fish oil biodiesel [10]. Preto et al. [11] considered the engine performance, ignition and emission attributes of fish oil fuel in a heavy-duty CI engine by differing the blends from 0% to 100% in the interim of 25% and half.

The test outcomes demonstrated that the engine worked typically guaranteeing its appropriateness as a beneficial fuel. Hence, the potential advantages of fish oil biodiesel are utilised in the study. Higher alcohols are less destructive on petrodiesel injection and conveyance courses of action because of their significantly less hygroscopic behaviour than ethanol getting consideration comprehensively. With its incredible miscibility with the petrodiesel, these higher alcohols are promising petrodiesel added chemical substances [12].

Higher Alcohols as a Biodiesel-Diesel Additive

Alcohols can be regarded as a clean blending element to diesel-biodiesel blends because they are renewable in nature. Redefining the biodiesel with the assistance of higher alcohols like n-pentanol is a practical choice to upgrade biodiesel properties all together to enhance the execution in petrodiesel engine applications. Extensive research has been done with short chain alcohols or low alcohols such as ethanol and methanol as additive to the proposed alternative fuel in CI engine systems. Nonetheless, longer chain or higher alcohols like n-butanol [7], [13], [14], n-pentanol [15] are getting growing focus on being used as a CI engine fuel by many researchers.

However, n-pentanol with five long carbon chain shows better fuel properties than ethanol, methanol and butanol. Furthermore, with its low polarity and hydrophobic nature the problem of phase separation in blends can be avoided [16]. With its excellent miscibility with diesel and vegetable oils, n-pentanol is becoming the researcher's choice in recent times. n-pentanol can also be a great green solution developed from renewable root. However, the reduced cetane number of higher alcohols is a limitation and it is important to enhance the same that for effective combustion and lower emission. Cetane number, one of crucial characteristic for the fuels of CI engines that ensure knocking-free combustion in the charge.

Thus, additives with a high cetane number fundamentally help in enhancing the overall efficiency of the engine [17]. The additive which is normally an oxygenated chemical, may also possess an added advantage of reducing the emission of hydrocarbon, CO and smoke of a CI system. Dimethyl ether, diethyl ether are such chemical substances comes under this category and offer wide range of benefits. Raza et al. [18] concluded in their work that the addition of pentanol along with Di-Methyl ether gave them better exhaust emissions in terms of reducing PM and NOx. Pan et al. [19] reported that the soot reduced drastically with pentanol blends with 2-EHN.

The fish oil methyl esters come up with reasonable cetane index that the cetane improvers can be ignored. This builds the scope for the novelty that the blends of fish oil biodiesel, n-pentanol with diesel as an alternative fuel option for a direct injection compression ignition engine. The prediction of the experimental paradigm by an artificial intelligent model like ANFIS adds significance to the originality.

The auto mobile manufacturers and application engineers have thought that it was hard to run the engine for all conceivable working states of burden and mix which is a tedious, complicated and costly task [20]. Mathematical models particularly artificial intelligent models help in reducing manual effort and improves quality [21]. Subrata et al. [22] compared Neural Network model with a ANFIS model and reported the superiority of ANFIS model. Singh et al. [23] announced that their RSM model is dynamic in enhancing the info parameters for a petrodiesel engine fuelled with biodiesel and petrodiesel mixes. With a low percentage error, the model is a proficient framework recognizable proof device and equipped for foreseeing the actual engine conduct with a praiseworthy exactness. Yusaf et al. [24] compared ANFIS with Support Vector Machine (SVM) and published that the ANFIS is advantageous over SVM.

To this degree, an express investigation fundamentally tending to the level of enhancing performance, emission trade-off view accomplished by offline alignment practices on existing Direct Injection CI engines under the skyline of existing outflow guidelines with higher alcohols like n-Pentanol is yet to be addressed. It very well may be closed from the thorough literature survey, just a bunch of works have been done, and the present examination shows a potential strategy dependent on demonstrating and streamlining that could analyze various blend structures for a Direct Injection CI engine and prescribe an appropriate blend exposure to no engine adjustments with sensible accuracy.

The present examination additionally conveys an ANFIS based prediction model using the engine responses of the DI engine with n-Pentanol percent, biodiesel percent, and load percent as inputs. The objective is to propose an appropriate fuel blend utilizing information factors, at the same time decreasing the engine responses like BTE, BSFC, NOx CO and UHC simultaneously has not been investigated yet. And thus an endeavor to investigate the emission performance paradigm of a single cylinder four stroke direct injection diesel engine, DICI naturally aspirated engine fuelled with different blends of diesel-biodiesel-additive blends is arranged to load this void.

Materials and methods

Preparation of Test Fuels

The transformation process of waste fish oil into fish oil methyl ester is done through a specific process called transesterification. The raw fish oil is heated to 50-60◦C and maintained steady state conditions. The basic catalyst KOH is added to the preheated raw oil and whole mixed up. Preheating avoids forming soap and thus allows to form pure methyl esters. The mixture is heated up to 70−80 ◦C during which the viscosity reduces drastically. The content which was allowed to settle overnight had a thick layer of glycerol at bottom separated by a mush of biodiesel, catalyst and some calculated measure of alcohol. To get the pure methyl ester, water wash with aqueous phosphoric acid (4% volume /volume%) is carried out. The content then was dried at 80 ◦C and observed for chemical stability before analysis. The transesterification process is depicted in the equation 1.

$$RCOOR' + R''O \leftrightarrow RCOOR'' + R'' \quad (1)$$

The methyl esters of fish oil, MEFO thus obtained is clear slightly orange yellow liquid with an intense smell. The methyl esters of fish oil, MEFO is kept under observation for 72 hours to check the phase separation issues before it is used to blend. The transesterification reaction [11], [25] is shown below. The test fuels were prepared with the diesel additive diethyl ether of analysis quality anhydrous DEE with 99.5% purity [15], n-pentanol of 99.9 % purity [26] and base fuel diesel are blended together in volume ratio as follows.

- m20p5= MEFO 20 % + 5% n-pentanol + 75 % Petrodiesel
- m20p10 = MEFO 20 % + 10 % n-pentanol + 70 % Petrodiesel
- m30p5 = MEFO 30 % + 5% n-pentanol + 65 % Petrodiesel
- m30p10 = MEFO 30 % + 10% n-pentanol + 60 % Petrodiesel
- Diesel= Diesel 100 %

The properties of the pilot fuels is demonstrated in Table 1.

Table 1: Properties of test fuels

Pilot Fuel	MEFO	m20p5	m20p10	m30p5	m30p10	ASTM
Density @ 20 $_o$C, g/cm$_3$	0.885	0.832	0.831	0.839	0.852	D4052
Kinematic Viscosity @ 20 $_o$C, mm$_2$/s	3.6	2.75	2.81	2.93	2.95	D445
Cetane number	52.6	49.995	49.5	50.125	49.73	D613
Calorific value, MJ/kg	40.1	43.03	42.87	42.76	42.16	D240

Table 2: Properties of base fuels [16], [18], [27]

Base Fuel	MEFO	Diesel	n-pentanol
Density @ 20 ^{o}C, g/cm^{3}	0.885	0.82	0.815
Kinematic Viscosity @ 20 ^{o}C, mm^{2}/s	3.6	2.5	2.89
Cetane number	52.6	51.3	20
Calorific value, MJ/kg	40.1	44	34.65

The engine selected for conducting the experiment is a 3.5 kW, Kirloskar make TV1 naturally aspirated engine water cooled model in the National Institute of Technology, Agartala. The engine is loaded with different mountings like an eddy current type dynamometer for measuring load, a crank angle sensor for measuring speed, a piezoelectric type pressure sensor to sense the in-cylinder pressures and an AVL five gas emission device that are detailed. The engine schematic diagram and valve timing diagrams were shown in Figure1 and Figure 2 respectively.

The inlet valve opening is at 4.5^{o} before Top Dead Centre and the exhaust valve is closing 4.5^{o} after Top Dead Centre creating a valve overlap of 9^{o} to the engine. Figure 2 illustrates the schematic diagram for the engine testing. The test rig is connected to a graphical user interface using a software "ENGINE SOFT" software was employed for estimating the temperatures of exhaust gas, water inlet and outlet, engine aspiration, fuel consumption, brake power, brake specific fuel consumption, etc.

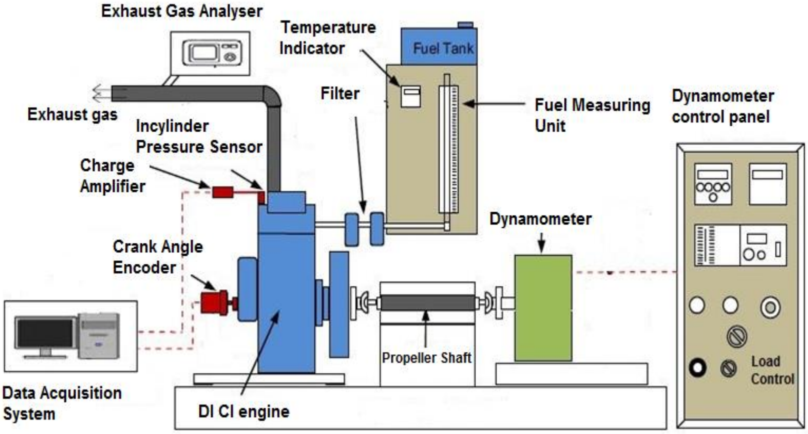

Figure 1: Schematic diagram of engine setup

An AVL 444 DI five gas analyzer is used to document the emission profiles. The test engine is fixed with the fuel injection at 27° before TDC. The technical details of the testrig are demonstrated in Table 3.

Table 3: Engine Specifications

Sl.	Engine Components	Specifications
1	Make	Kirloskar Oil Engine Ltd.
2	Model	TV1
3	No. of Cylinders	1
4	No. of Strokes	4
5	Bore Dia.	87.5 mm
6	Stroke Length	110 mm
7	Compression Ratio	17.5
8	Cylinder Volume	661 cc
9	Cooling System	Water Cooled
10	Fuel Oil	H. S. Diesel
11	Lubricating Oil	SAE 30/SAE 40
12	Fuel Injection	Direct Injection
13	Governing	Class "B1"
14	Start	Hand Start
15	Rated Output	3.6 kW
16	Rated Speed	1500 RPM
17	Overloading of Engine	10% of rated output
18	Lub. Oil Sump Capacity	3.7 Lt
19	Injection pressure	205 bar

Results and discussions

Performance analysis

BTE: Brake thermal efficiency

BTE is straight representation of the efficiency, which takes chemical energy present in the fuel converted into some form of work. It is also the ratio of engine brake power to the input of chemical fuel energy [28].

$$BTE = \frac{Engine\ Brake\ Power}{Fuel\ consumed\ per\ second \times Calorific\ value} \quad (2)$$

Figure 2 depicts the variation of the engine response concerning the brake power developed at different loads. All the pilot fuels are proved to be worthy with respect to the engine response. The test rig is fuelled with different pilot fuels prepared with the methyl esters of Fishoil MEFO and the pentanol additive and a steady increase in thermal efficiency can be seen as the load increases. The m20p10 blend is giving maximum performance at all loads. The blend registered 6.28% more than petrodiesel at full loads. The reason for the rise in brake thermal efficiency is the oxygen portion in blend having pentanol and MEFO, which enhances the combustion.

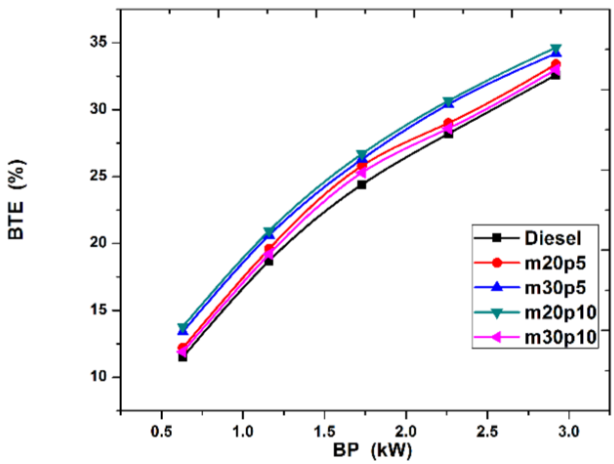

Figure 2: BTE versus BP

BSFC: Brake Specific Fuel Consumption

The parameter signposts the quantity of fuel to be expended per unit power output [28].

$$BSFC = \frac{Pilot\ fuel\ flow\ into\ the\ engine\ in\ kg/hr}{BP} \tag{3}$$

Variation of the engine response concerning the brake power developed at different loads is shown in Figure 3. It can be perceived that it decreases gruffly with the increase in brake power for all blends. The primary foundation for the reduction in BSFC could be regarded to increment in brake power which is because of relatively less quantity of heat losses were recorded at higher loads. All the pilot blends and petrodiesel were confirmed decreasing with increasing brake power and hence load share. It is because of the higher part of the increase in brake power concerning load in comparison with the rise in fuel consumption. The effect of Fish oil methyl ester and n-pentanol on the engine responses depends on the association between the fuel properties like fuel oxidation time, kinematic viscosity of the sample, calorific values and proper fuel injection strategies. More amount of fuel enters into the cylider due to higher density of the pilot fuels and increased the fuel consuption. Lower heating values due to the addition of n-pentanol also increased the consumption. Figure 4 depicts that m20p10 recorded a 1.3 % higher consumption than other petrodiesel. The combined effects of density, cetane number, heating value and kinematic viscosity are the reason behind the higher BSFC [29].

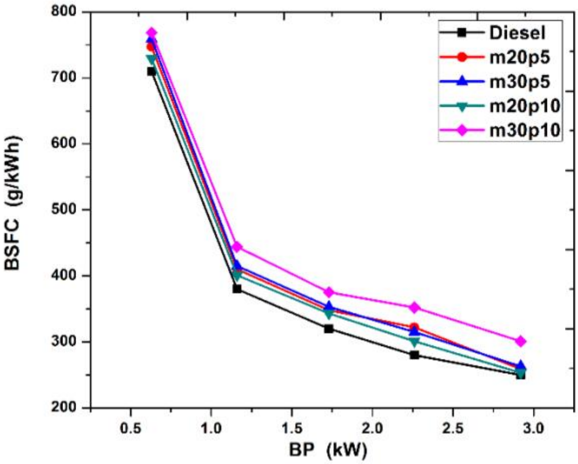

Figure 3: BSFC versus BP

NOx: Nitrogen emissions

NOx is one of the critical factors that are linked directly to environmental issues like global warming. In-cylinder temperature, oxygen quantity in fuel sample and, equivalence ratio are some crucial factors that influence the formation of NOx. Variation of the engine response concerning the brake power developed at different loads is shown in Figure 4. Around 5% reduction is seen with the m20p10 blend at full loads which was a significant achievement in the experiment. The main reason for this increase in NOx concerning its load conditions can be given by Zeldovich reaction mechanism [28] which says, by elevated combustion temperatures inside combustion chamber attributable to which the elements like oxygen and nitrogen dissociate within their natural atomic state, react chemically to form NO.

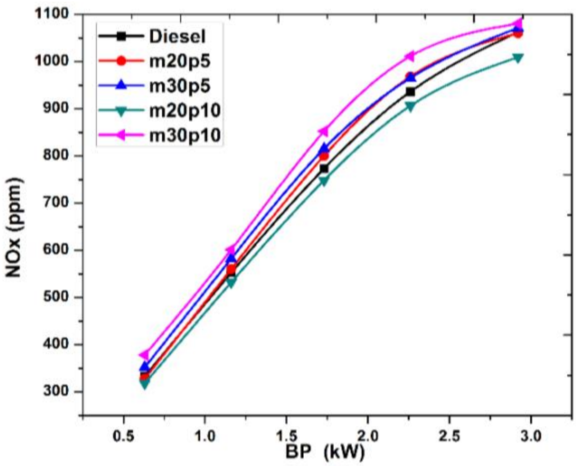

Figure 4: NOx versus BP

CO: Carbon monoxide

The variations of CO emission with respect to Brake Power for various fuel blends are shown in Figure 5. It can be understood from the graph that at low loading condition, the CO emission from the engine does not show any noticeable variations when compared to petrodiesel. An abrupt increase in the response is noticed in all fuel blends at higher loading conditions. The noble benefit of adding higher alcohol like n-pentanol can be seen. However, addition of n-pentanol in the pilot fuels decreased the CO emission significantly. Lower C/O ratio of n-pentanol benefited the fuel blend in producing lower CO as less carbon radicals participated in chemical combustion inside the cylinder. In addition to this, the decomposition of n-pentanol and higher oxygen in the also helped CO to oxidized to CO_2. It was also observed that CO emission increased significantly with m30p10 blend having 10% pentanol. Adding pentanol with 10% pentanol was found to reduce CO emission significantly. It is a well-known fact that CO oxidizes to produce CO_2.

In Figure 5, it is clear that the blend m30p10 is giving least CO emissions as it recorded 23% and m20p10 is producing 13.1% lesser CO emission than petrodiesel when compared.

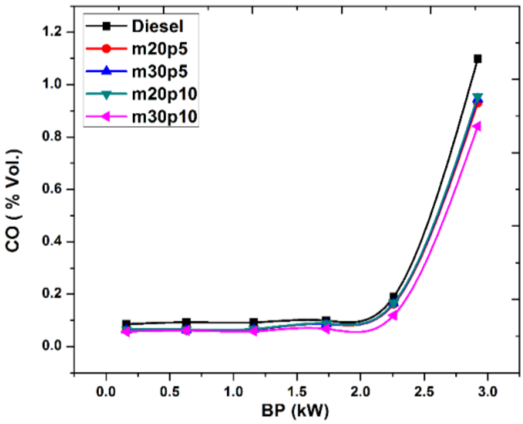

Figure 5: CO versus BP

UHC: Unburnt hydrocarbons

Unburnt hydrocarbons are due to the absence of relatively limited oxygen present in the combustion chamber and excess quantity of fuel sample injected inside the combustion chamber at high loads. The production of unburnt hydrocarbons is a definite consequence of incomplete combustion and gets deposited on the walls of the combustion chamber. Variation of the engine response UHC concerning the brake power developed at different loads is portrayed in Figure 6 in which the addition of higher alcohols reduced the UHC production is depicted. The m30p10 is giving 25.2% lesser UHC and m20p20 is giving 17.3% lesser than petrodiesel.

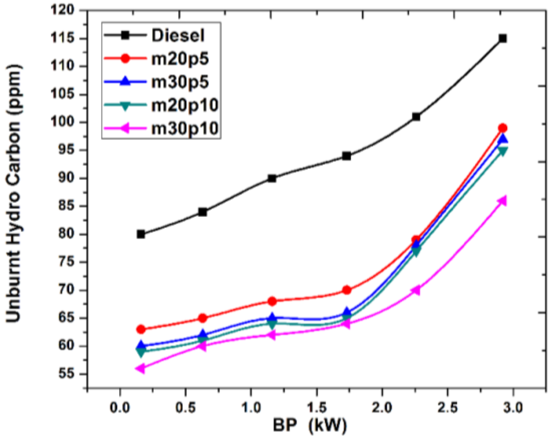

Figure 6: UHC versus BP

Trade-off Study

Trade-off study is principally a relative appraisal among several parameters to discover the significance of a specified metric in the landscape of the other ones.

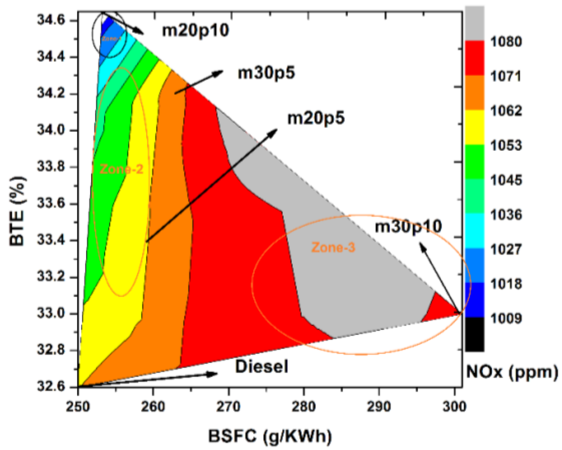

Figure 7: Trade-off among BTE, BSFC and Nox

The current trade-off analysis deals with an extensive investigation acknowledged on variations in NOx relating Brake Thermal Efficiency, and fuel consumption, and oxides of nitrogen, which has been shown in Figure 7. The tradeoff area is divided into three zones. In zone-1 the minimum NOx with bluish shades are considered, the greenish-yellow hues are considered as zone-2 representing medium NOx, and the reddish grey shades are regarded as higher NOx production in zone-3. For 20% MEFO blends with pentanol, the presence of pentanol in the pilot fuel considerably increased the BTE and reduced the BSFC and NOx simultaneously can be depicted in the trade-off area as m20p5 in zone-2 shifted to zone-1 for m20p10. The reason might be the optimum oxygen percentage in the pilot fuel, and the lower vapour pressure of the additive limited the peak temperature rise in the combustion chamber. It can be seen in 30% fish oil methyl ester blends that the addition of higher alcohol increased not only the fuel consumption but also the NOx formation. The BTE is also suffered drastically. It can be concluded from the trade-off study that the presence of higher alcohol not only benefited the 20% MEFO blends but also increased with the increase of higher alcohol percentage.

ANFIS as a system identification tool

Fuzzy inference system (FIS) as the basis of ANFIS is a technique concerning with fuzzy rules that are engaged to derive a new approximated fuzzy-set inference while captivating fuzzy-set as a foundation [30],[31]. Fuzzy inference system is predominantly enforced to the circumstances that either the system is complex to be quite sculpted or the depiction about the reviewing issues are equivocal and confusing [27]. An ANFIS model has the following components

- A grid of some entailing IF-THEN rules.
- A decision-making component that executes the inference system of rules.
- A fuzzification system interface, transferring the input of the system to a fuzzy ruled set processed by fuzzy inference system unit.
- A defuzzification system interface, swapping the fuzzy ruled conclusion to the original output.

FIS is employed to converge input criterion to membership functions (MFs), later on these input MFs into a bunch of if-then rule metrics, rules into a grid of output responses, output responses into output MFs, and finally the output MFs to output or a decision linked with the output response [32]. A typical ANFIS model comprises of five layers with and a two input factors x, y and one response K is demonstrated in Figure 8. The very first one is a fuzzy layer in which membership functions are constructed. The following equation gives a membership function for a node I with a node function Φ.

$$K_i^1 = \Phi_{F_i}(y) \tag{4}$$

where y is an input to the node I, Fi is a membership function for the output K. Triangular, and bell-shaped MFs are common. The second layer is the product layer in which it acts as a simple multiplier. The output of the node can be depicted as:

$$K_i^2 = \alpha_i = \Phi_{F_i}(y) \times \Phi_{F_i}(x) \text{For i =1, 2, 3,…etc} \tag{5}$$

α_i are called the firing strengths of all rules framed. The normalised layer is the third layer and is given by the ratio of firing strength to the total strengths.

$$K_i^3 = \overline{\alpha_i} = \frac{\alpha_i}{\alpha_1 + \alpha_2} \text{For 1, 2, 3, …etc} \tag{6}$$

The fourth layer being the defuzzyfying layer in which the consequential parameters further process the output of the third layer and are given by:

$$K_i^4 = \bar{\alpha}_\iota g_i = \bar{\alpha}_\iota(a_i x + b_i y + r_i) \text{For i=1, 2, 3,…etc} \quad (7)$$

The last and final layer is summing junction where all input signals were added up.

$$K_i^5 = \sum_{i=1}^{2} \bar{\alpha}_\iota g_i = \frac{\sum_{i=1}^{2} \alpha_i g_i}{\sum_{i=1}^{2} \alpha_i} \quad (8)$$

In general, the two adaptable parameter criterion sets, {a_i, b_i, c_i} termed as premise parameter criterion and {p_i, q_i, r_i} termed as consequent parameter criterion are in practice. The goal of training algorithm intended for this particular architecture is to adjust the overhead parameter criterion sets to sort the ANFIS response output that maps the training data. The proposed ANFIS model supports the Sugeno-type architectures and should have the following properties:

1. The structure should be Sugeno type.
2. All rules should have equal and unit weightage value.
3. All membership functions should be either linear or constant type.
4. No rule sharing among membership functions.

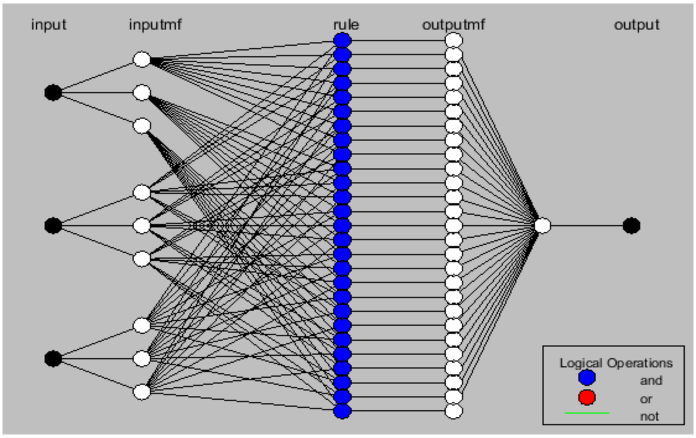

Figure 8: ANFIS Structure

The principal limitation of the ANFIS models is with the number of input factors. Beyond five inputs, the computational time and rules will increase, so ANFIS will not be prepared to model output concerning data. In this study, three input factors used and five output responses are used. Depending on the nature of the problem, the choice of various membership functions, nature of MFs (triangular, Gaussian trapezoidal, sigmoid, and bell-shaped), type of output MFs (linear or constant), optimization approach (hybrid or back propagation) and finally the number of epochs produce a robust and competent model.

The entire experimental dataset is separated into two major classes explicitly training, and validation sets and therefore 70% of the entire experimental dataset is arbitrarily designated for training, and the residual data set is used for performance investigation of the generated ANFIS model. The MATLAB-16 toolbox is employed for building the designated ANFIS model. At this juncture, the grid partitioning practice is employed to create the Sugeno based FIS structure to launch a relationship among the input factors, and output responses contingent on specific framed rules and an optimum training of the neuro-fuzzy algorithm is contingent on hybrid learning technique. As the training program is completed the performance of the Sugeno is estimated by serving the input dataset to the fuzzy interface system, and the engine response can be characterized with reference to correlation matrix among the actual and predicted data.

Performance evaluation

The performance of the network was evaluated using some special statistical error metrics like correlation coefficient (R), mean absolute percentage error (MAPE) and root mean square error (RMSE). These error metrics are often defined concerning the predicting error, the difference between actual response and the predicted response and that could be seen by commissioning Equation 8, 9, and 10.

$$R = \sqrt{1 - \left\{\frac{\sum_{i=1}^{n}(e_i - p_i)^2}{\sum_{i=1}^{n}(p_i)^2}\right\}} \tag{9}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(e_i - p_i)^2}{n}} \tag{10}$$

$$MAPE = \sum_{i=1}^{n}\left|\frac{e_i - p_i}{e_i}\right| \text{x} \frac{100}{n} \tag{11}$$

where p_i and e_i are individual predicted response and the actual response of the i_{th} iteration and n is the sample size of the dataset. By the previous literature, the values R>0.98, MSE<0.001 and MAPE<5% are healthy for a robust model [22]

Evaluation of ANFIS model and Error Analysis:

The model seems to be robust as the mathematical parameters like R, RMSE and MAPE appear to be an acceptable threshold. Based on this research, the

Regression values are ranging from 0.9967 to 0.9999 (Very close to unity) that shows the agreement of the predicted data with the experimental data. The RMSE is ranging 0.000026 to 0.0000336 (shallow values) which shows the homogeneity among the data and MAPE is very low ranging from 0.0021 to 0.0028.

Conclusions

The experimental investigation that was piloted to find the possibility of Fishoil methyl ester as an alternative to petrodiesel. Based on the experimental observations the following conclusions were drawn.

1. The pure fish oil methyl esters resulted in higher specific fuel consumption and lowered thermal efficiency when compared to petrodiesel. The reason is due to low volatility and higher kinematic viscosity of Fishoil biodiesel than conventional fuels.
2. Dilution of MEFO with petrodiesel in varying proportions resulted in reducing kinematic viscosity significantly, which was further reduced by adding n-pentanol in the blends.
3. MEFO along with n-pentanol, and its blends with petrodiesel oil were compatible with petrodiesel at higher loading conditions from the perspective of engine performance.
4. Physical and chemical properties test revealed that the Fishoil methyl ester blends have almost all properties similar or better than that of the petrodiesel fuel, except viscosity which is slightly higher than that of petrodiesel suitable as fuel for CI engines without any engine modification.
5. Brake thermal efficiency results show improvement for all MEFO blends and m20p10 shows better results among all with 6.28% higher than petrodiesel.
6. Emission test shows a reduction in per cent of CO and HC in exhaust gases for m30p10 and m20p10 fuels concerning diesel oil at higher power output.
7. The blends of fish oil methyl ester and diesel m20p10 proved promising as an alternative to petrodiesel fuel for running the CI engine with less emission of NOx, CO and HC and better engine performance.

The proposed model with ANFIS found robust as the mathematical parameters like R, RMSE and MAPE are located in an acceptable threshold.

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