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Full Length Article

Prediction of CI engine performance, emission and combustion characteristics using fish oil as a biodiesel at different injection timing using fuzzy logic

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HIGHLIGHTS

- Combustion analysis of fish oil biodiesel.
- Comparison of engine performance of fish oil biodiesel with base diesel.
- Fuzzy modeling to predict the engine performance.

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ABSTRACT

The present study investigates the potential of Fuzzy Inference System (FIS) to predict the performance, combustion and exhaust emissions of the Compression Ignition (CI) engine at different injection timings (21°, 24°, 27°bTDC) using fish oil biodiesel. The experimental investigations are carried out on a single cylinder constant speed direct injection diesel engine under variable load conditions. Here Multi Input Multi Output (MIMO) fuzzy models are developed, trained and validated to predict the parameters like Brake Thermal Efficiency (BTE), Hydrocarbon (HC), Exhaust Gas Temperature (EGT), Oxides of Nitrogen (NOx), Carbon monoxide (CO), Smoke, Carbon dioxide (CO_2), Ignition Delay (ID), Combustion Delay (CD) and Maximum Rate of Pressure Rise (MRPR) with the experimental performance data sets using Trapezoidal membership function. The developed MIMO fuzzy model is capable of predicting the performance, emissions and combustion parameters of the engine with better correlation coefficients in the range of 0.946–0.999, mean absolute percentage error in the range of 0.06–4.5% with noticeably low root mean square errors. The validation results confirm the applicability of the developed FIS models with high degree of accuracy and minimum time demand that can effectively replace the costly and time consuming real life experiments and trails.

1. Introduction

The global thirst for energy is constantly increasing. The energy requirement of the world is projected to increase by 50% from 2005 to 2030, as predicted by International Energy Outlook, 2008. In the present scenario, fossil fuels dominate the world energy market occupying 26–27% each of total energy consumption as predicted by International Energy outlook, 2030 [1]. According to U.S. Energy Information Administration (EIA), International Energy Statistics database, the average global energy consumption grows at the rate of 1.6% p.a, which leads to the search for alternate fuels that can replace or supplement conventional fossil fuels. Biodiesel is a promising alternative source for the diesel with similar properties [1,2] that can be used in regular diesel engine without making much changes [2,3]. Biodiesel can be produced from renewable resources such as vegetable oil, animal fats and waste cooking oils [3,4].

While considering the biodiesel from vegetable oil, cultivation of crops for biodiesel production poses a threat to food security and contributes to decline in soil fertility. The oil percentage and the yield per hectare of vegetable oil are very low. On the other hand, waste cooking oil from restaurants and domestic kitchens is not a continuous source of raw material for biodiesel fuel [5]. Thus, one of the prominent alternative fuels is the biodiesel obtained from animal fat. Biodiesel can be obtained from less expensive animal fat such as inedible beef fat, pork fat, duck fat, fish fat and yellow grease [6]. The animal fat present in the waste parts of fish serves to be a good source of crude oil for biodiesel. It

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Table 1
Fuel properties of diesel and biodiesel blends.

Properties	Diesel fuel	Ethyl Ester of Fish Oil and its blends with diesel				
		B100	B80	B60	B40	B20
Density (kg/m^3)	850	885	879	869	860	852
Kinematic viscosity at 40 °C (Cst)	3.05	4.741	4.52	4.36	4.22	4.1
Calorific value (kJ/kg)	42,800	40,057	40,517	40,973	41,388	41,844
Flash point (°C)	56	114	98	79	63	44
Fire point (°C)	63	125	107	90	72	52
Cetane index	52	52.6	–	–	–	–

Table 2
Fuel properties of test fuels and other fish oil biodiesels.

Properties	Godiganor et al. [8]	Shiratori et al. [30]	Lin and Li [10]	Behcet [12]	Giakoumis [31]	This study
Density (kg/m^3)	880	862	860	881	887.3	885
Kinematic viscosity at 40 °C (Cst)	4.0	4.85	7.2	4.451	4.3	4.741
Calorific value (kJ/kg)	42,241	39,700	41,370	40,546	40,550	40,057
Flash point (°C)	176	149	103	155	162.6	114
Fire point (°C)	–	–	–	–	–	125
Cetane index	–	–	50.9	52.4	51	52.6
Oxygen content (%)	10.9	–	7.19	–	–	7.3

is estimated that, every year, a surplus amount of fish parts is discarded by various fish products manufacturing industries. As per department of Animal Husbandry, Dairying & Fisheries, Govt. of India, 20% of the total fish produced is discarded as waste. In India, currently 38 fish waste processing plants are operating in various coastal states (CIFT). The annual fish oil production from three states (Tamil Nadu, Kerala and Karnataka) of India was 34,000 tonnes [39]. The global fish oil production was 1.01 million tonnes as stated by International Fishmeal and Fish Oil Organization (IFFO). Since large quantities of waste parts are discarded, the complete recycling of these discarded parts is a high priority concern, not only due to the large quantities being generated, but also due to their economic and environmental problems [4]. Fish oil can be derived from waste parts of fish like viscera, eyes, fins, head, tails, liver and maw [7]. Consequently, crude fish oil extracted from these discarded parts may provide an abundant, cheap, and stable source of raw oil.

Several researchers had used fish oil biodiesel as an alternate fuel and discussed its performance and emission characteristics. Godiganur et al. [8] analyzed the performance and emission characteristics of diesel engine operated with methyl ester of fish oil and its blends with diesel. The test results showed no major deviations in diesel engine combustion as well as performance but a reduction in main noxious emissions like CO and HC with the exception on NOx was noticed. For B20 blend, lower BSFC, BSEC and higher BTE compared to diesel was obtained. There was no significant change in the engine performance but a reduction of main noxious emissions was observed [4,9]. CO and CO_2 emissions were

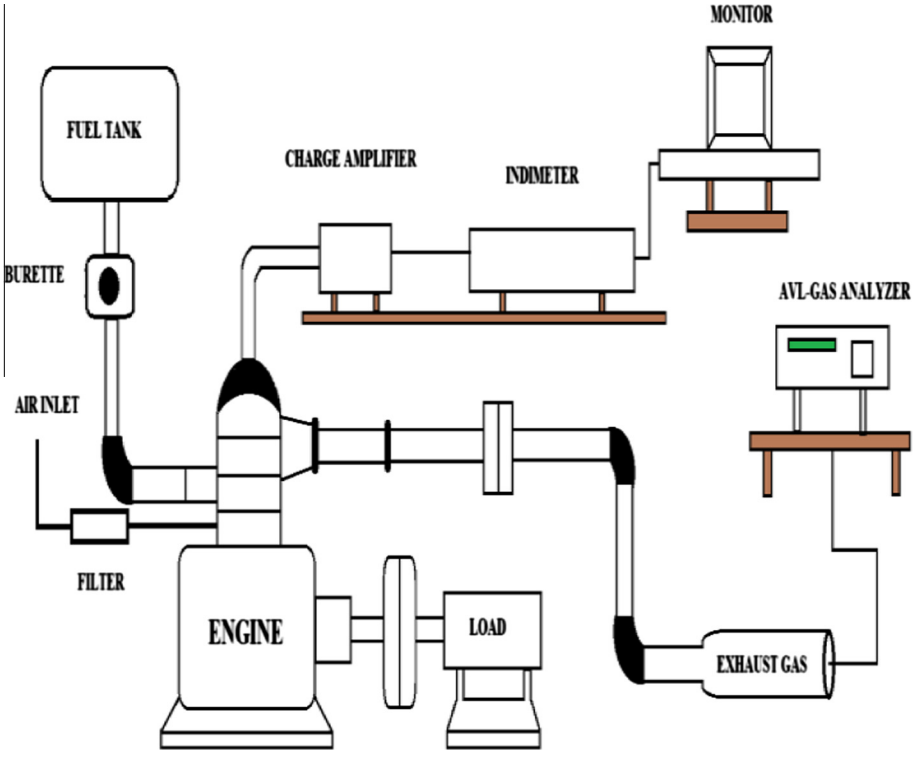

Fig. 1. Experimental setup of the production of the fish oil.