Energy 140 (2017) 566–583

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A decision support system to evaluate the optimum fuel blend in an IC engine to enhance the energy efficiency and energy management

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ARTICLE INFO

Article history:
Received 28 February 2017
Received in revised form
27 July 2017
Accepted 12 August 2017

Keywords:
Energy
MCDM
Fish oil
Diesel
Fuzzy set theory
TOPSIS
VIKOR

ABSTRACT

The demand for the energy has increased drastically as a result of the rapid growth in industrialization, urbanisation and higher standard of living. One such potential substitute to fossil fuels is biodiesel that ensures sustainable energy source. The selection of appropriate source of biodiesel and proper blending of biodiesel plays a major role in alternate energy production. In the present work, a novel hybrid Multi Criteria Decision Making (MCDM) technique was proposed to evaluate and select the optimum fuel biodiesel blend for the IC engine with conflicting criteria to enhance the energy efficiency. Exploratory analysis were carried out on a single cylinder four stroke, air cooled, constant speed, direct injection diesel engine with a rated output of 4.4 kW at 1500 rpm at different loads. Two hybrid MCDM models, namely Fuzzy TOPSIS and Fuzzy VIKOR were proposed. Fuzzy was applied to determine the relative weights of the evaluation criteria whereas TOPSIS and VIKOR were applied to obtain the final ranking of alternatives. Diesel, B20, B40, B60, B80 and B100 fuel blend alternatives are prepared by varying the proportion of biodiesel for MCDM model. Similarly BTE, MRPR, NO_x, CO_2, CO, HC, SMOKE, ID, CD and Exhaust gas temperature were considered as the evaluation criteria. The ranking order by Fuzzy TOPSIS is based on closeness coefficient and Fuzzy VIKOR is based on VIKOR index. In Fuzzy TOPSIS, B40 stands first at 50% and 75% load conditions and second at 25% and full load conditions respectively. In Fuzzy VIKOR, B40 stands first at 25% and 50% conditions and second at no load, 75% and full load conditions respectively. The ranking of alternatives as obtained by both Fuzzy-TOPSIS and Fuzzy-VIKOR is B40 > B20 > Diesel > B80 > B60 > B100 and B40 > B20 > Diesel > B60 > B80 > B100. From the results, it was observed that both the methods indicated that B40 is the best blend to operate the engine. Hence, it is concluded that mixing 40% biodiesel with diesel is suggested as a good partial replacement for diesel. This paper highlights a new insight into MCDM techniques to evaluate the best fuel blend for the decision makers such as engine manufactures and R& D engineers to meet the fuel economy and emission norms to empower the green revolution and energy management.

1. Introduction

Energy is the primary parameter which directly impacts the country's economy as stated by World Trade Organization. According to International Energy Information Administration, a projection has been made that the oil resources would be sufficient enough to meet the demand up to 2030. (Energy outlook, 2030). Astonishing advances in industrialization and transportation, building, and innumerable other technologies in the world has led to a steep rise for the demand of petroleum-based fuels. But, the energy consumption continues to increase with the growth of world population leads to energy depletion and environmental degradation. In order to address both these problems of energy requirement and energy depletion, the search for a viable alternative fuel was carried out. Biomass fuels are the convincing alternative for the fossil fuels which guarantees energy security but also provides renewable, biodegradable and 100% natural fuel with properties similar to diesel. It also reduces global warming and environmental meltdown occurring due to massive carbon footprints left by the fossil fuels. Considerable research work is going

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http://dx.doi.org/10.1016/j.energy.2017.08.051
0360-5442/

List of abbreviations

MCDM	Multi-Criterion Decision Making
FAHP	Fuzzy Analytical Hierarchy Process
TOPSIS	Technique for Order Preference Similarity to Ideal Solution
VIKOR	VIse Kriterijumska Optimizacija I Kompromisno Resenje (in Serbian)
NO_x	Oxides of Nitrogen
CO_2	Carbon dioxide
CO	Carbon monoxide
BTE	Brake Thermal Efficiency
HC	Hydrocarbons
EGT	Exhaust Gas Temperature
ID	Ignition Delay
CD	Combustion Duration
MRPR	Maximum Rate of Pressure Rise
CC	Closeness Coefficient
CI	Consistency Index
CR	Consistency Ratio
IS	Ideal Solution
NIS	Negative Ideal Solution
RCI	Random Consistency Index
RI	Random Index
f_i^*	Best value
Ci	Criterion
A^*	Ideal Solution
A	Negative Ideal Solution
$\tilde{r}_{ij}$	Normalized fuzzy decision matrix
Rij	Normalized value
aij	Rating of the ith maintenance strategy on deducting changes in the jth criterion using suitable measure
R_i	Regret measure
CC_i	Relative closeness coefficients
D_j^*, D_j	The distance between the performance scores of alternatives with respect to all criteria
Si	Utility measure
Q_i	Vikor index
f_i^-	Worst value
f_i^*	Best value
VL	Very low
ML	Medium low
L	Low
F	Fair
H	High
MH	Medium high
VH	Very high
VP	Very poor
MP	Medium poor
P	Poor
F	Fair
G	Good
B0	Diesel 100%
B100	Ethyl ester of fish oil 100%
B20	Ethyl ester of fish oil 20%: Diesel 80%
B40	Ethyl ester of fish oil 40%: Diesel 60%
B60	Ethyl ester of fish oil 60%: Diesel 40%
B80	Ethyl ester of fish oil 80%: Diesel 20%

around the globe in search of alternative renewable fuels for diesel engines. The important advantages in using biodiesel as an alternate fuel is that it can be used as a fuel in a diesel engine without any modification.

Biodiesel can be produced from renewable resources such as vegetable oil, animal fat and waste cooking oil [1]. The cultivation of crops for biodiesel production poses a threat to food security and contributes to decline in soil fertility [2]. On the other hand, the animal fat present in the waste parts of fish serves to be a good source of crude oil for biodiesel. Jayasinghe and Hawboldt (2012) reviewed the properties of biofuel from fish and suggested that it exhibits better engine performance [3]. A few researchers have used fish oil as a biodiesel to study the performance and emission characteristics of Internal Combustion (IC) engine [4–15]. Hence an attempt has been made to use ethyl ester of fish oil as a biodiesel to study the performance, exhaust emissions and combustion parameters. Sustainability of biodiesel is also the key factor for using it as a fuel in diesel engines Evaluation of suitable blend is based on the performance, emission and combustion parameters of the engine. It is quite difficult to choose the optimum blend to run the Internal Combustion (IC) engine with respect to different load conditions for different biodiesel-diesel blends. In the existing work, most of the researchers have discussed their operating fuel with reference of NOx, smoke and BTE performance. Based on the reduction of NOx and smoke and increase of BTE, the operating fuel is recommended as the best blend without considering other influencing parameters such as HC and CO [16–18]. In this paper, to overcome the shortcomings of the existing research, all the performance, emission and combustion characteristics are considered.

The conventional testing of engine for fuel blends under all possible conditions is more complex, time consuming and expensive at different load conditions with different fuel blends. Modelling of the engine operation using optimization technique is the alternate method to meet out the aforementioned requirements. There are a few studies in literature with regards to the investigation of optimum blends ratios of biodiesel blends using artificial neural network (ANN), response surface methodology (RSM). Engine performance characteristics are optimised using ANN which has been gradually increasing over the period of a few years [42–46]. Taguchi method, Response surface methodology and Factorial design methods are also proposed by the researchers to improve the engine performance characteristics and exhaust emissions and to identify the best possible blend ratios in a diesel engine without any engine modification [47–50]. In the existing work, most of the researchers have discussed their ANN, RSM and Taguchi technique to optimize the engine performance but there is no attempt made by the researchers to choose the optimum blend to run the IC engine using MCDM.

MCDM provides sophisticated methodological tools that are oriented towards the support of the decision makers in facing complex real-world decisions. The application of MCDM in IC engine has been gradually increasing in the past few decades. Poh and Ang (1999) applied an AHP technique to identify and evaluate the best alternative fuel for land transportation in Singapore [19]. Janic and Reggiani (2002) applied SAW (Simple Additive Weighting), TOPSIS(Technique for Order Preference Similarity to Ideal Solution) and AHP to evaluate the selection of new hub airport [20]. Winebrake and Creswick (2003) have predicted the future of hydrogen fuelling systems for transportation using multi-criteria decision making method with Analytical Hierarchy Process [21]. Tzeng et al.