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Diesel engine performance and emission characteristic enhancement using TOPSIS

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Abstract
The demand for fuel is increasing, and the availability of fossil fuel reserves is limited. The amount of concern arising from the emission problems causing the environment and ecosystem are increasing exponentially. It requires the industry to find the optimum solution. Biodiesel can be stored and used as petroleum diesel. It can be used in blended or pure forms without any modification in the engine. Use of bio-diesel has shown a remarkable reduction of toxic emissions and noise and emissions. This research deals with the use of Jatropha oil as biodiesel to improve the emission characteristics; at the same time, the performance characteristics need to be improved. The diesel engine is optimized with different blends of Jatroha oil as biodiesel, compression ratio, and load using L27 orthogonal array of full factorial design of experiment. The emission parameters, such as HC, CO, and CO2 are measured. The performance parameters viz brake power, brake thermal efficiency, specific fuel consumption, and volumetric efficiency are calculated. The entropy method determines the weight. Optimization is performed using multi-criteria decision-making technique with the TOPSIS method. The results show that blend B10 and a compression ratio of 15 found to be the optimum setting for diesel engine using biodiesel blends to optimize the performance.

Keywords
Biodiesel, Diesel engine, Design of experiment, Entropy method, MCDM, TOPSIS.

1.Introduction
The German scientist Rudolph Diesel was a pioneer in the development of fuel injector-based combustion engine. Diesel and gasoline engines, both were crucial in the development of the automobile sector and the transportation industry [1]. Comparing with a gasoline engine, a diesel engine offers advantages of low fuel consumption, high durability, and high thermal efficiency [2]. Worldwide the market share of diesel-powered goods vehicles is increasing, and every third car buyers choose diesel-powered vehicles [3]. On the other side, compared to the conventional catalyst equipped gasoline engine, a diesel engine is a significant contributor of particulate matter and nitrogen oxide (NOx) emissions.

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The combustion efficiency of a diesel engine improves as injection pressure increases [4]. This is due to the better atomization and mixing of fuel and air [5].

The development in the diesel engine was carried out to improve the engine performance and reducing the emissions due to stringent emission norms. One of the methods of controlling NOx emissions is with the help of exhaust gas recirculation (EGR) [4]. As the number of holes in the injector increase, it turns improves the diesel engine performance [6].

The demand for fuel is increasing, and the availability of fossil fuel reserves is limited. The environmental pollutions in the form of greenhouse gas (GHG) emissions, NOx, polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM), and smoke increased significantly in the last decade. This puts a challenge on researchers to discover renewable energy source, alternative fuels in diesel engines, and to improve its performance [7]. Bio-oils such as edible and non-edible oils can be considered as the possible alternative fuel sources since these are readily available and are biodegradable [8, 9]. Researchers have been focusing on non-edible oil, mostly due to the food security issue. Use of bio-diesel has shown the remarkable reduction of the toxic emissions and noise [10], reduced GHG emission [11], lesser NOx emissions, PAHs, PM, and smoke [12, 13].

Most importantly, the conventional diesel engine can be used without any modifications with bio-diesel [14]. Use of bio-diesel is limited because of its lower heating value and Cetane number, higher density (ρ), higher kinematic viscosity (μ) and surface tension (σ) compared to diesel [15]. The combustion chamber geometry plays a vital role in improving engine performance. Introduction of a small percentage of biodiesel improves the emission characteristics with a small reduction in engine performance [16].

Multi-criteria decision-making techniques (MCDM) are used by researchers in the past to identify best performing parameters of the biofuels. Analytical network process (ANP) and the technique for order performance by similarity to ideal solution (TOPSIS) is used to evaluate the optimum blend [17]. Erdogan and Sayin determined weights using step-wise weight assessment ratio analysis (SWARA) and multi-objective optimization based on ratio analysis (MULTIMOORA) to rank alternative fuels according to fuels' characteristics [18]. Akbas and Bilgen presented interaction of the fuzzy analytical network process (FANP) and fuzzy analytic hierarchy process (FAHP) to decide the weight of the attributes and TOPSIS connected to fuzzy quality function deployment (FQFD) to select the ideal gas fuel at wastewater treatment plants [19]. Sivaraja et al. identified the fuel blend using hybrid multi-criteria decision making (MCDM). The study concluded that the results significantly increased the efficiency of the decision-making process to identify the optimum fuel blend by minimizing noxious emissions [20].

In this paper, the experimentation is performed on the single cylinder diesel engine with a different blend of Jatropha oil as biodiesel. Moreover, the load and compression ratio is varied to confirm the engine performance as well as emission characteristics of the diesel engine. MCDM approach is used to find the optimum solution. As the engine performance parameters like brake power (BP), brake thermal efficiency (BTHE) should be maximized and emission parameters like hydrocarbon (HC), carbon monoxide (CO), brake specific fuel consumption (BSFC) should be minimized. Therefore, multi-criteria decision-making approach can be a more suitable method for optimizing performance pre-masters with different nature. MCDM methods like VIKOR, simulated annealing (SA), Extended PROMETHEE II (EXPROM2), Ashby, etc. are used widely by researcher earlier [21−24]. The objectives of the study to apply TOPSIS to find the best set of parameters meeting the criteria. TOPSIS is given less attention by earlier researchers to optimize the input parameters in the biodiesel study. Hence this study uses an entropy approach to determine weights and TOPSIS to select the best-operating settings.

2.Materials and methods

A single cylinder, four strokes, variable compression ratio (VCR) diesel engine connected to a hydraulic type dynamometer for loading is used for the experimental setup. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with the necessary instrumentation to measure combustion pressure and crank-angle.

The real-time data can be obtained through a computer interface for P θ−P V diagrams. Provision is also made for airflow, fuel flow, temperatures, and load measurement. A stand-alone panel box with air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator are available for the measurements. Cooling water and calorimeter water flow can be measured using Rotameters provided. VCR engine performance can be studied for BP, indicated power (IP), frictional power (FP), brake mean effective pressure (BMEP), indicated mean effective pressure (IMEP), BTE, indicated thermal efficiency (ITHE), mechanical efficiency (ME), volumetric efficiency (VE), specific fuel consumption (SFC), air-fuel (A/F) ratio and heat balance. A lab - view based Engine Performance Analysis software package "EnginesoftLV" provides for online performance evaluation. A computerized Diesel injection pressure measurement is optionally provided. Figure 1 shows the VCR, diesel engine test setup. Figure 2 shows the schematic diagram of the experimental setup.

Table 1 Factors and levels for Jatropha biodiesel

Factors	Levels		
	1	2	3
Blends % (A)	B10	B20	B30
Load (kg) (B)	3	6	9
Compression (C) Ratio	15:1	16:1	17

Figure 1 VCR, diesel engine test setup

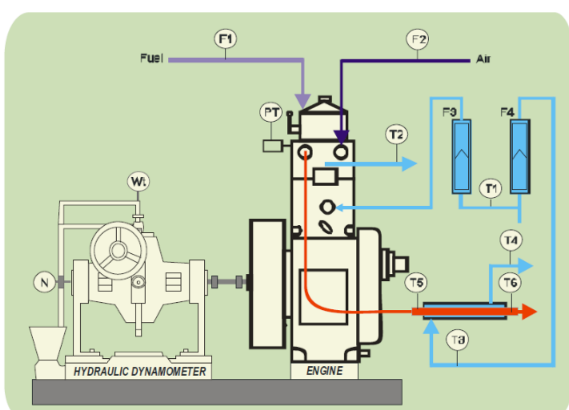

Figure 2 Schematic diagram of Experimental setup

2.1Design of experiments

The experiments were performed using three input factors viz. blend percentage of Jatropha biodiesel with diesel, load, and compression ratio. To formulate experiments and analyze the design of experiments is used by the researcher in the past [25−27]. Three levels of each input parameter were selected based on experience and literature survey as shown in *Table 1*. Full factorial design of the experiment is utilized for 3 factors 3 levels L27 array is used for the experiment design as illustrated in *Table 2.*

The output parameters measured with the experimental setup are described in *Table 2*. The emissions responses measured are HC, Carbon dioxide (CO2), and CO. Also, performance responses like BP, BTHE, SFC, and VE are measured.

Table 2 Design of experiment by Full Factorial Method

Expt No	Blend (A)	Load (B)	CR (C)
1	B10	3	15
2	B10	6	15
3	B10	9	15
4	B10	3	16
5	B10	6	16
6	B10	9	16
7	B10	3	17
8	B10	6	17
9	B10	9	17
10	B20	3	15
11	B20	6	15
12	B20	9	15
13	B20	3	16
14	B20	6	16
15	B20	9	16
16	B20	3	17
17	B20	6	17
18	B20	9	17
19	B30	3	15
20	B30	6	15
21	B30	9	15
22	B30	3	16
23	B30	6	16
24	B30	9	16
25	B30	3	17
26	B30	6	17
27	B30	9	17

The Measured values for various parameters using Jatropha Biodiesel is shown *Table 3*

2.2Entropy method

Entropy method is a measure of uncertainty in information formulated in terms of probability theory. The concept of entropy is discussed in thermodynamics by Rudolph Clausius (1865) and is a measure of the degree of disorder in a system. It is an objective weighting method which uses probability theory to measure uncertainty in output responses. It utilizes the responses of each criterion to determine the weighted [28−30].

The steps followed by the entropy method to determine the weights are shown in *Figure 3*. *Table 3* shows the emission and performance testing results.

Here,i represents Experiment Number; j is the output response number , m represents the total number of Experiments and n represents the total number of output responses β is the weightage of corresponding jth response.

Table 3 Weightage for output response

HC	CO	CO_2	BP	BTH	SFC	VE
0.1504	0.1451	0.1526	0.1402	0.1285	0.1266	0.1562

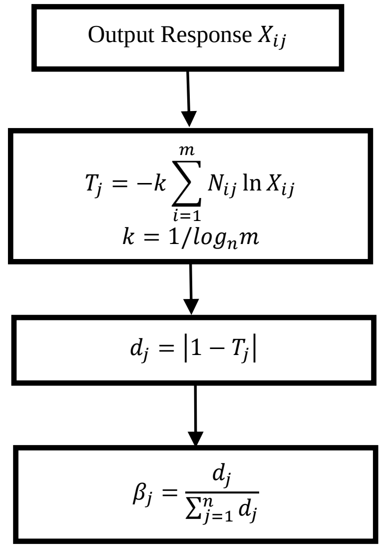

Figure 3 Flow chart of entropy method

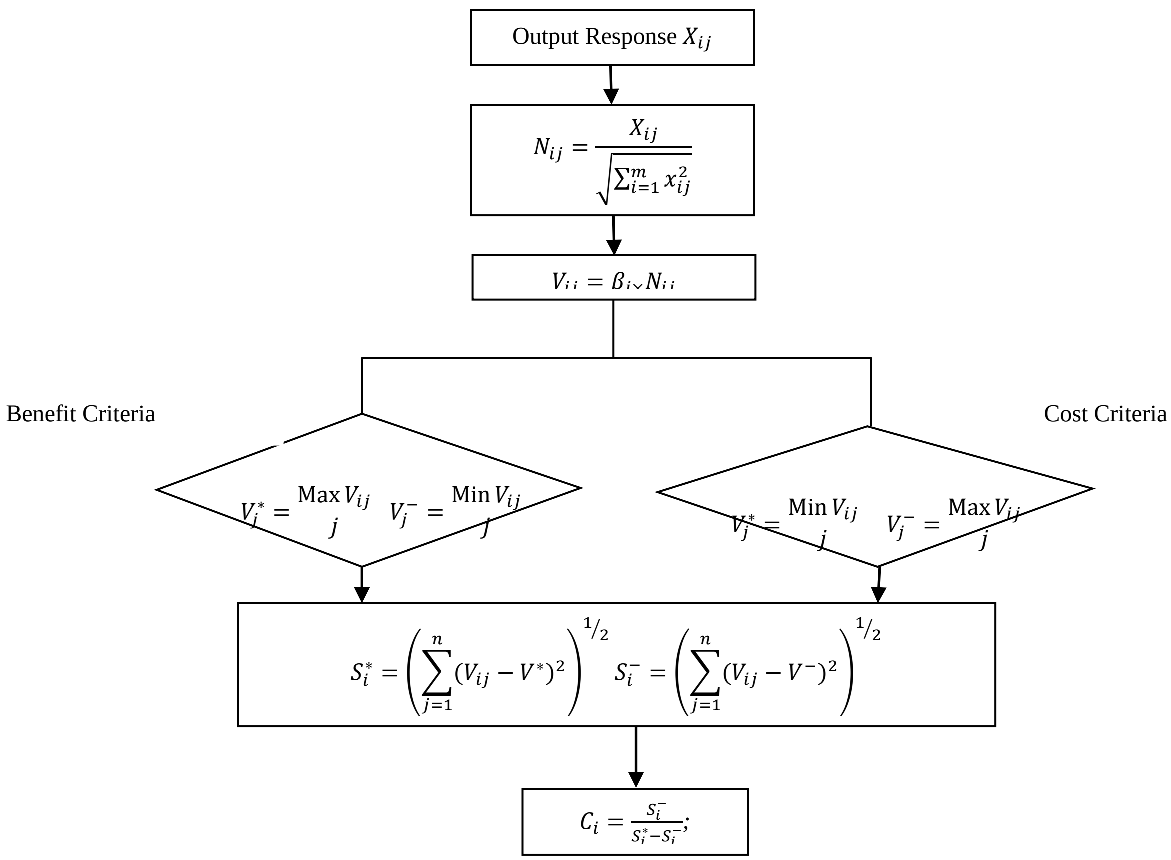

Figure 4 Flowchart for TOPSIS method

The weightage of each response for respective biodiesel is provided in *Table 4*.

2.3TOPSIS method

TOPSIS method is generally used to find the preference ranking of all alternatives. It uses the output response of each criteria and converts the multi-criteria system into single output response in the form of preferential index. The value which is close from the ideal solution, according to benefit and cost situation of all criteria will be used respectively [30−34]. The TOPSIS index (Ci) is calculated as illustrated in *Figure 4.*

Here, i is number of experiments, j represents output response number, m is the total number of experiment and n represents the total number of output response β is the weightage of corresponding jth response which is calculated by using entropy method for a blend of the biodiesel. Very important step in the TOPSIS method is to normalize the output so that value of each response will get converted between 0 and 1. The weighted normalization is carried out by multiplying with weights of respective output response obtained with help of entropy method. Each response is analyzed so that the multi output response is converted into a single output response according to output response Criteria function. The descending order of output response gives ranking, which helps to find the best setting of the input parameters.

The TOPSIS method analysis of diesel engine with various blends of biodiesel and diesel is shown in *Table 4*. The TOPSIS analysis shows that the experiment number 3 is having the highest rank as per the criteria provided.

3.Results

The Entropy Method, as described in the above section utilized on the output responses of a diesel engine. The L27 experiments array with the output response gives the weight as tabulated in *Table 4* the addition of all the weights to be always one.

Table 4 Weightage for output response

HC	CO	CO_2	BP	BTH	SFC	VOLE
0.1504	0.1451	0.1526	0.1402	0.1285	0.1266	0.1562

The TOPSIS method described in the above section used to convert a multi-output response into single grade output, which is used to decide the best experiment. The positive ideal solution, harmful ideal solutions, closeness index, and rank are tabulated for 27 experiments in *Table 5*.

Table 5 TOPSIS coefficients and ranking for Jatropha biodiesel

Expt. No	Si*	Si'	C	Rank
1	0.0574	0.0215	0.2726	21
2	0.0361	0.0378	0.5110	11
3	0.0126	0.0613	0.8296	1
4	0.0658	0.0055	0.0772	26
5	0.0467	0.0237	0.3368	18
6	0.0254	0.0489	0.6586	9
7	0.0597	0.0122	0.1692	23
8	0.0396	0.0313	0.4420	14
9	0.0189	0.0541	0.7406	5
10	0.0667	0.0042	0.0588	27
11	0.0455	0.0250	0.3547	17
12	0.0243	0.0520	0.6814	7
13	0.0600	0.0120	0.1669	24
14	0.0395	0.0313	0.4424	13
15	0.0186	0.0560	0.7504	4
16	0.0653	0.0061	0.0851	25
17	0.0446	0.0271	0.3778	15
18	0.0246	0.0522	0.6798	8
19	0.0522	0.0258	0.3305	19
20	0.0393	0.0314	0.4442	12
21	0.0145	0.0617	0.8100	2
22	0.0581	0.0235	0.2880	20
23	0.0448	0.0260	0.3670	16
24	0.0211	0.0592	0.7372	6
25	0.0533	0.0200	0.2724	22
26	0.0346	0.0363	0.5121	10
27	0.0180	0.0548	0.7531	3

4.Discussion

The output responses are tabulated in *Table 3* gives the best result of a respective output response, which is in pink color shade. It is essential to understand that the results give the confusion in selecting the best setting for the performance of the diesel engine.
In this study blend of Jatropha biodiesel is used to understand the performance of the diesel engine. The Taguchi design of experiments L27 array is used to perform the experiments. Engine emission and Performance characteristics measured and tabulated in *Table 3*. The weights of emission and performance characteristics parameters are calculated using of entropy method. The entropy method uses interrelation of output values with each other. It is observed that the volumetric efficiency is assigned with the highest and specific consumption found to be the lowest weight of 0.1562 and 0.1266, respectively. The weights calculated were further used for TOPSIS analysis. In TOPSIS analysis, positive ideal solution (PIS) and negative ideal solution (NIS) for L27 experiments are calculated

and tabulated in column 2 and 3 of *Table 5*, respectively.

The closeness index is used to decide the rank of experiments which shows the best performance. The input parameter values of experiment number 3 give the best performance considering multiple output parameters with closeness index 0.8206. The results show that blend B10, load 9 kg, and CR 15 found to be the optimum setting for diesel engine using biodiesel blends.

5.Conclusions

In this study, various blends of Jatropha biodiesel & diesel is used to measure the performance parameters of a single cylinder diesel engine. Parameters studied are HC, CO, CO2, BP, SFC, VE. These parameters are conflicting in nature as some emissions & SFC are to be minimized and BP and VE to be maximized. Hence MCDM techniques can be useful to find the best parameter setting given improved performance. Here, Entropy method is used to find the weight of the parameters under study, and TOPSIS is used to find the best set of the input parameters. From the entropy analysis, volumetric efficiency found to be having the highest weight while specific fuel consumption received the lowest weight. Following points can be concluded from the above study.

- The weight found by using entropy method for Jatropha gives volumetric efficiency the highest weight output.
- The entropy method uses the interrelation between the output responses, hence the weight obtained is reliable.
- Similarly, TOPSIS method also gives optimum parameter setting for Jatropha is A1B3C1 (Blend B10, Load 9 kg, and Compression ratio 15.

Future work can be carried out for methods to improve volumetric efficiency by using different types of combustion chambers with less clearance volume. This will increase the amount of charge, accommodated in the engine, which improves brake power. Also, due to the formation of homogeneous mixture HC, CO emissions can be reduced.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

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