A Multi-Objective Optimization of Output Parameters of a Single Cylinder Diesel Engine Running Methyl Esters and Different Additives: Taguchi-Fuzzy Based Approach

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ABSTRACT

The continuous dependency on fossil fuels for energy requirements, transportation and power generation sectors the research has increased considerably on alternative source of fuel. Recently, it can be seen that Madhuca Indica Methyl Ester is gaining popularity due to its economical nature, the similarity with diesel's properties. The primary aim of this research is to implement blends of Machuca Indica biodiesel using two different additives, 2-EHN and triacetin in different ratios for investigating single cylinder direct injection diesel engine output. In the current analysis, a Taguchi optimisation technique based on fuzzy logic is used to find the optimal combination of emission and performance parameters in order to make prediction of optimal input blends. It shows that the cylinder pressure of the blends is always higher than diesel. Among all blends, BL2 possesses the highest cylinder pressure under various load conditions. In terms of brake thermal efficiency, Among the blends, BL2 and BL3 possess BTE 12%, and 11% more than plain diesel in full load respectively. At maximum load, BSFC of Blend 2, 3 and 6 are (25, 22.5, 20)% less than plain diesel. BL5, BL6 and BL7 produced 3%, 1% and 0.3% less NOx than diesel. It is seen

ISSN 1823-5514, eISSN 2550-164X

Received for review: 2020-04-02
Accepted for publication: 2020-12-11
Published: 2021-01-15

that BL2, BL3 and BL5 had lowermost UHC emission of 34%, 27% and 26% than pure diesel at maximum load. This multi-objective optimization technique shows that the blend BL6 have optimal MPCI value of 0.75.

Keywords: *Madhuca Indica Methyl Ester, Multi-objective optimization, Diesel additive, Performance, Emission.*

Introduction

Fossil fuel depletion and environmental deterioration are two major problems that the world is facing nowadays. Oil contributes the largest share of the world economy. Almost 180 million barrels of oils are used every day around the world [1]. According to Peak oil concept, the demand for oil will beat supply, and this gap will advance to the rise of the deficiency that will result in growing energy crisis between 2010 and 2050 [2, 3]. Sustainability of energy is one of the most important issues that can affect the politics and economy of the world [4-7]. Even if for power and heat applications conventional energy source is considered as the main source of energy, increased awareness regarding environmental problems and continuously depleting conventional resource is creating a need for alternative fuels which are non-conventional and from renewable sources [7-10]. Non-conventional fuel can be derived from thermoelectric, thermo ionic or thermochemical conversion and renewable energy sources. Since biodiesel is available in large volume, biodegradable and non-toxic is best suitable as a renewable fuel. Biodiesel due to its miscibility with both diesel and alcohol have been as appropriate for combinations with ethanol or methanol as alternate fuels for achieving better performance and lesser emission [11-13]. Several biofuel varieties have been tried and tested by the researchers and the industry lately. However, Madhuca Indica oil due to its economical nature, the similarity with diesel's properties, and large scale availability have caught the limelight. Therefore, a fuel with high oxygen content, high cetane number and low amount of additives could play a significant role for better output. In this experimental study, 20% (by volume) two different biodiesel were combined with both plain diesel and additives in the required quantity to make seven different blends for further analysis.

Only experimentation does not guarantee the optimal blend. Therefore we need to move towards statistical analysis for finding the best combination of parameters for optimizing cost and time factors. fuzzy optimization focusses on solving of the fuzzy model optimally through optimization tools and techniques based on the formulation of fuzzy information in terms of the possibility distribution function, their membership functions etc. The methods used by Taguchi are statistical methods created by him to enhance the manufactured goods quality. It gives us the optimal operating conditions to reduce the influence of the noise factor. As we cannot control the noise we modify the factors within our control to reduce what we cannot control. This helps to reduce random fluctuation caused by noise factors and achieving more consistent product. According to Taguchi, S/N ratio is an assessment of performance stability of an output characteristic which considers both averages as well as variation. However, directly implementing this method is not possible in a multi-objective optimization problem. So, previously, other theories like desirability function approach, grey relation theory and utility theory [9] were combined with the Taguchi method. Practically, assigning individual responses priority weights are based on assumptions and it won't lead to an optimum solution and may lead to uncertainty. To solve this problem the fuzzy-based Taguchi method is adopted. It is understood that many research works were carried out using different biodiesel and its blends with additives by adopting fuel and engine modifications. Most of them reported that higher NOx emission in diesel engines when the blends were used as fuels. It is observed that no research work was carried out on the utilization of 2-Ethylhexyl nitrate, triacetin with the Machuca Indica oil in diesel engines, to study the NOx reduction. The primary objective of the research of next-generation alternative fuels are:

- To prepare the different blends using surfactant and characterize them as fuels for the engine.
- To analyses the combustion, the heat released, performance and emission characteristics of unmodified diesel engine by using blends of two different additives and Madhuca indica methyl ester.
- To analyses the different input blends and predict the optimum among them using Taguchi fuzzy optimization technique.

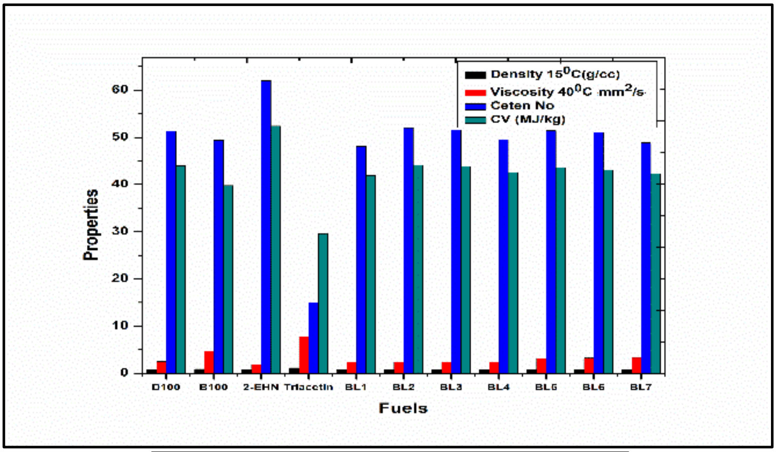
Methodology

Fuel selection

Biodiesel is an alternative for fossil fuels from 100% renewable sources. An important class of organic reactions, where an ester is altered into another ester by interchanging alkyl groups is termed as Transesterification. Equation (Transesterification Reaction) (1) is shown below:

$$RCOOR' + R''OH \leftrightarrow RCOOR'' \quad + R'\,OH \qquad (1)$$

The oils used in this study were neat diesel, Madhuca Indica Methyl Ester (MIME) of 99.9% purity [13]. 2-Ethylhexyl nitrate (2-EHN) is usually used with a blend of diesel to rise its cetane number [14, 15]. Triacetin is a highly oxygenated additive to fuel which can be used in the combustion process. After producing the required amount of the methyl ester from vegetable oil and collecting necessary diesel additives, their properties were established according to IS test methods in Figure 1.



D100	100 % Diesel
BL1	(08+12) % Diesel, MIME
BL2	(04+08+16) % 2-EHN, Diesel, MIME
BL3	(06+08+14) % 2-EHN, Diesel, MIME
BL4	(08+08+12) % 2-EHN, Diesel, MIME
BL5	(04+08+16) % Triacetin, Diesel, MIME
BL6	(06+08+14) % Triacetin, Diesel, MIME
BL7	(08+08+12) % Triacetin, Diesel, MIME

Figure 1: Fuel properties.

Apparatus, Used (Performance and Emission)

The experimental setup uses water-cooled four-stroke, single-cylinder DI engine operating on diesel as shown in Figure 2 and the specification in Table 1. Different load conditions can be provided, i.e. (0, 3, 6, 9 and 12) kg on the engine, which leads the load range from no load to full load. The exhaust emission (CO, NOx, HC) for the experiment was analyzed (Testo-350). The instrument consists of the analyzer box and the control unit. The specifications of the gas analyzer are given below in Table 2. For the experiment, eddy current dynamometer was attached with the engine and allowed to run for 30 minutes using plain diesel for warming up.

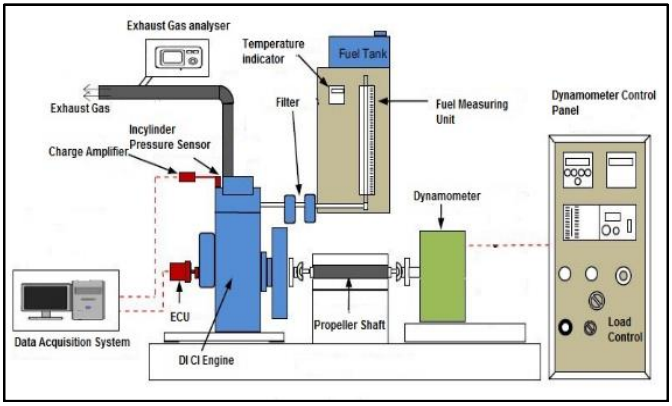


Figure 2: Experimental setup.

Table 1: Engine Specification

Make and type	Kirloskar, cylinder (One), Diesel (Four Stroke)
Engine type	CI Engine (Vertical Type)
Stroke length (mm)	110
Swept volume (CC)	661
C.R.(Compression ratio)	17.6
Power	3.5 kilowatts
Rated speed (RPM)	1500
Dynamometer	
Make	Power Mag
Type	Eddy current
Load measurement method	Strain Gauge
Maximum load	12-kilogram
Cooling	Water

Table 2: Precision for Testo 350

Apparatus Testo-350	Accuracy of instrument	Range
HC	< 400 ppm (100 to 4000 ppm) < ten % of mv (> 4000 ppm)	100 to 40,000 (ppm)
NOx	±5 ppm (0 to +99 ppm) ±5 % of mv (+100 to +1999.9 ppm) ± 10% of mv (+2000 to +3000 ppm)	0 to 4000 (ppm)

Results & Discussion

Cylinder pressure

In Figure 3, the deviations in the cylinder pressure (maximum) with biodiesel (MIME), D100, and additive (2- EHN, triacetin) blends are shown. It shows that the cylinder pressure of the blends is always higher than diesel. Among all blends, BL2 possesses the highest cylinder pressure under various load conditions. This could be due to the diesel additive's property (high cetane number & low auto-ignition temperature) [16-17].

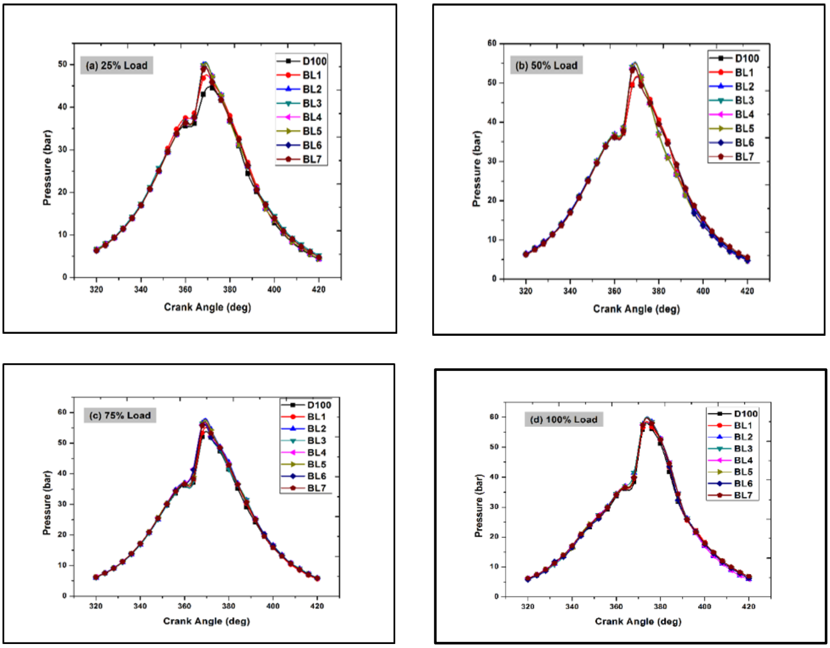


Figure 3: Cylinder pressure and load.

B.T.E. (Brake thermal efficiency)

Input chemical energy in the form of fuel converted to useful work is known as BTE [10]. Figure 4 shows that for every blend, BTE increases on increasing the load. Among the blends, BL2 and BL3 possess BTE 12%, and 11% more than plain diesel in full load respectively. This rise can also be due to better combustion of the fuel blend because of its higher cetane number, higher oxygen content, and higher flame velocity in the biodiesel and additive [18].

B.S.F.C. (Specific fuel consumption)

The quantity of fuel needed for producing 1- unit of energy by the engine is called BSFC. At maximum load (Figure 5), BSFC of Blend 2, 3 and 5 are (25, 22.5, 20)% less than plain diesel because of low density and heating value of biodiesel and diesel additives, which lead to lower consumption of fuel while producing same output power. The output parameters of the blend rely on the association between fuel injection system and properties of fuel (high viscosity of the biodiesel, low calorific value, oxygenation) [19- 20].

NOx (Oxides of nitrogen)

At 100% load (Figure 6), emission of NOx was found to be 4%, 2.1% and 3.6% more in BL1, BL3 and BL4 respectively. Due to high combustion temperature, oxygen and nitrogen molecules present in fuel ionize to form NO which is considered to be the key cause in the formation of NOx. But BL5, BL6 and BL7 produced 3.3%, 1% and 0.3% less NOx than diesel due to the fact that additive triacetin present in them possesses high latent heat of vaporization and low heating value that decreases the cylinder temperature. Thus due to triacetin, less heat will be generated (cooling effect) during combustion [21].

U.H.C. (Unburned hydrocarbon)

The increase in UHC Can be blamed for incomplete combustion of fuel which is directly related to the presence of oxygen in it. If there is less amount of oxygen in the fuel mixture, the hydrocarbons do not react completely that produces more unburned HC. It is seen from Figure 7, that BL2, BL3 and BL5 had lowermost UHC emission of 34%, 27% and 26% than pure diesel. The blends used in our experiment contain additives which increased its cetane number and improved combustion and reduce the emission of UHC considerably [22, 23].

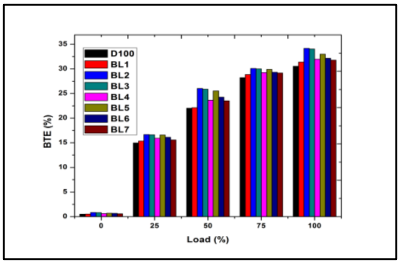


Figure 4: BTE with load.

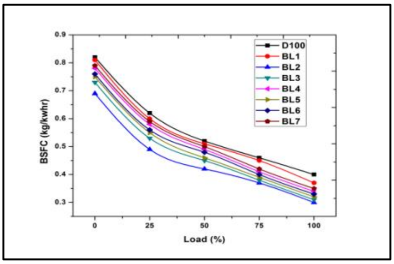


Figure 5: BSFC with load.

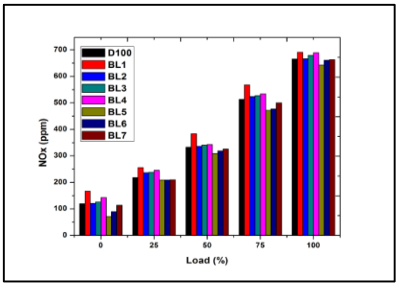


Figure 6: NOx with load.

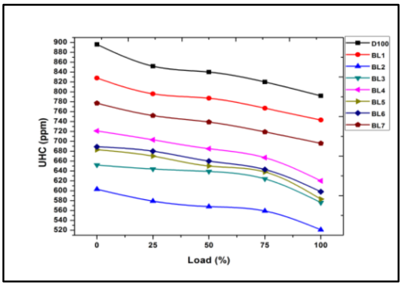
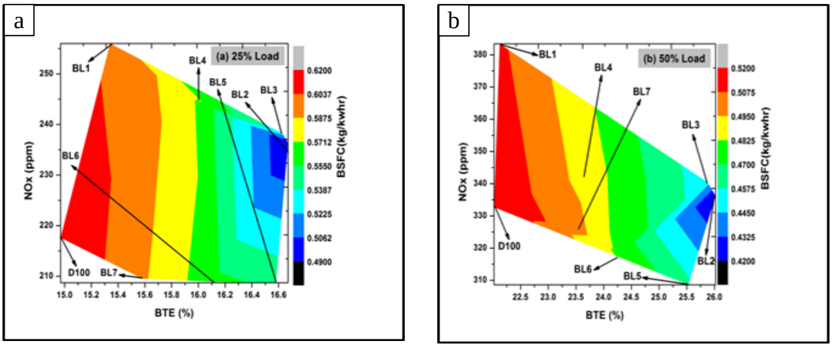


Figure 7: UHC with load.

Trade-off (BSFC- BTE- NOx)

In 25% load the parameters like BTE, BSFC and NOx are analyzed (Figure 8 (a)). As compared to diesel, BL1 and BL4 had slightly higher BTE. While in BL2, BTE and NOx are more which move the tradeoff area to top. Now in 50% load condition, Figure 8 (b) shows the same pattern of increase in NOX and BTE for some blends i.e. while raising the quantity of biodiesel and additive in it, the tradeoff region moves towards the top. Now considering a load of 75% we can visualize the pattern in which NOx, BSFC and BTE vary in different blends with different additives and Methyl esters (Figure 8 (c)). It is observed that in BL2 and BL3 having supplemented with 2- EHN and MIME, the NOx and BTE produced is higher while BSFC or fuel consumed is lesser. Though for BL5 and BL6, NOx and BSFC got reduced and BTE got intensified. Now, the result of varying the usage of MIME, 2-EHN and triacetin in various diesel blends are visualized in Figure 8 (d), in case of full load. It is seen that BSFC decreases but when BTE rises NOx also goes up. On the other hand, BL2 shows high emission of NOx and BTE but fairly low BSFC as portrayed in the top area of the graph. Interestingly BL6 shows the optimum tradeoff zone with higher BTE and lower BSFC and lowest NOx emission.



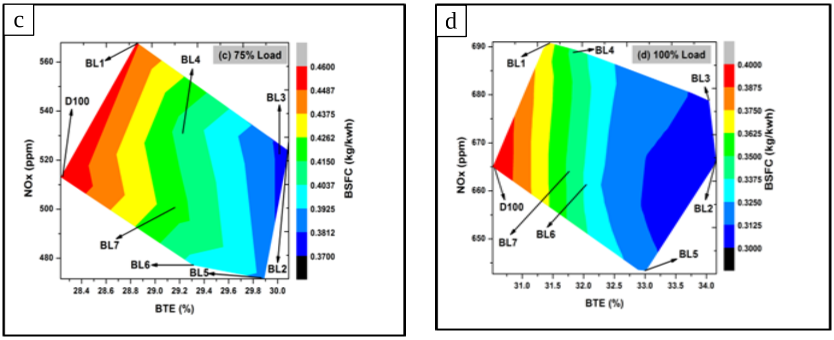


Figure 8: Trade-off study (BSFC- BTE- NOx).

Fuzzy based Taguchi optimization

The methods used by Taguchi are statistical methods created by him to enhance the manufactured goods quality. It gives us the optimal operating conditions to reduce the influence of the noise factor. According to Taguchi, S/N ratio is an assessment of performance stability of an output characteristic which considers both averages as well as variation. However, directly implementing this method is not possible in a multi-objective optimization problem. So, previously, other theories like desirability function approach, grey relation theory and utility theory [24-26] were combined with the Taguchi method. Practically, assigning individual responses priority weights are based on assumptions and it won't lead to an optimum solution and may lead to uncertainty [15]. To solve this problem the fuzzy-based Taguchi method is adopted. Also, there is a clear idea regarding the current workflow in Figure 9.

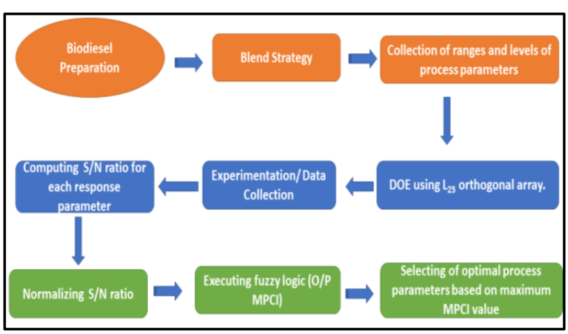


Figure 9: Flowchart for current workflow.

Optimum parameter selection of multi-objective optimization

For operating smoothly in the experimentation, forty permutations are provided in an L40 orthogonal array arrangement for a diesel engine between the different blends B and load A as explained in Table 3. This problem can be resolved in a direct manner which is implied by the fact that statistics was not in much focus; rather, S/N ratio was considered for handling the orthogonal array. The frequency of experiments conducted were observed to reduce and, optimal experimental arrangements were defined with the usage of Taguchi's technique for determining only a single characteristic. Larger the better and smaller the better are two methods through which the S/N ratio is found for analysing the factor effects numerically [9, 15, 21]. Thus from among all the quality characteristics (BSFC, BTE, UHC, and NOx), one of the quality characteristics can have its own set of process factor arrangement. Equation 2 is adopted to find the S/N ratio of 'larger-the-better' for BTE [16].

$$S/N = -10\,Log\,\frac{\sum_{i=1}^{n} y_i^2}{n} \quad (2)$$

Equation 3 S/N ratio of "smaller the better" for BSFC, UHC, and NOx [23].

$$S/N = -10\,Log\,\frac{\sum_{i=1}^{n} \frac{1}{y_i^2}}{n} \quad (3)$$

Here 'n' is the number, y measures i^{th} characteristic

Statistical analysis

Before the last step, i,e. normalisation process (Equation 4), various blends and loads were used for calculating the S/N ratio (average performance emission and emission) for the four parameters cited above using Taguchi techniques. The change of process parameter level with a change in BSFC, BTE, UHC and NOx (output properties) are depicted in signal-to-noise response graphs [9, 22-23] and the value range of signal-to-noise ratio shows a variation with output parameters of the engine.

$$X_{Normalized} = \frac{(X_i - X_{Min})}{(X_{Max} - X_{Min})} \quad (4)$$

Table 3: Taguchi's orthogonal array (L_{40})

Sl. No	A	B	BSFC (Kg/kwh)	BTHE (%)	NOx (PPM)	UHC(PPM)
1	0	D100	0.82	0.5	119.6	896
2	0	BL1	0.81	0.52	166.9	828
3	0	BL2	0.69	0.83	120.9	603
4	0	BL3	0.73	0.81	125.6	652
5	0	BL4	0.78	0.62	142.2	721
6	0	BL5	0.75	0.69	71.3	683
7	0	BL6	0.76	0.67	89.6	689
8	0	BL7	0.79	0.58	113.7	777
9	25	D100	0.62	14.97	217.6	852
10	25	BL1	0.6	15.34	256	796
11	25	BL2	0.49	16.67	236.3	579
12	25	BL3	0.53	16.63	238.2	644
13	25	BL4	0.58	15.9	245.8	703
14	25	BL5	0.55	16.58	208.7	670
15	25	BL6	0.56	16.12	208.9	680
16	25	BL7	0.59	15.58	209.5	752
17	50	D100	0.52	22.02	332.7	840
18	50	BL1	0.51	22.12	383.4	787
19	50	BL2	0.42	26.02	336.2	568
20	50	BL3	0.45	25.87	340.5	639
21	50	BL4	0.49	23.65	342.8	685
22	50	BL5	0.46	25.53	308.6	650
23	50	BL6	0.48	24.26	319	660
24	50	BL7	0.5	23.52	325.6	739
25	75	D100	0.46	28.23	513.1	820
26	75	BL1	0.45	28.85	567.9	767
27	75	BL2	0.37	30.09	523.8	559
28	75	BL3	0.38	29.99	527	624
29	75	BL4	0.41	29.24	533.6	667
30	75	BL5	0.39	29.89	471.6	638
31	75	BL6	0.4	29.31	477.2	643
32	75	BL7	0.42	29.16	500	719
33	100	D100	0.4	30.52	665	792
34	100	BL1	0.37	31.39	691	743
35	100	BL2	0.3	34.16	666	521
36	100	BL3	0.31	34.04	679	576
37	100	BL4	0.34	31.97	689	620
38	100	BL5	0.32	32.98	642.7	583
39	100	BL6	0.33	32.14	661	598
40	100	BL7	0.35	31.78	663	696

Considering Xi to be the S/N ratio and range of i starts from 0 ,1, 2….n. The maximum and minimum values of signal to noise ratio are denoted by Xmax and Xmin in the equation. Figure 10 represents the triangular member function which is used to obtain the optimum MPCI (max) by using an optimisation process (fuzzy) in output and input variables. The optimum value of MPCI has to be extracted next by using fuzzy techniques and Table 4 will give the optimum emission factor and performance for the study. Figure 11 (A, B, C, D) shows the combination of the different parameters and its effect on S/N ratio. Input combination [Load (0%), Fuel (D100)] for BSFC by projected amount of 2.974 (Least value among all S/N ratios), input [Load (100%), Fuel (BL2)] For BTE with a value of 30.629 (Highest value among all S/N ratios), input [Load (100%), Fuel (BL2)] in terms of NOx value stated -60.624 (lowest value among all S/N ratios) and input [Load (0%), Fuel (D100)] In terms of UHC, the projected value is -58.80 (lowest value among all S/N ratios). For both the input and output level, different fuzzy (eighty-one) rules are set out of which few are shown in and Table 5. After the response value is obtained, this method converts it to its equivalent S/N ratio. Taking input for load and fuel as 100 percent and BL2, the highest value obtained for MPCI is 0.75 displayed through simulation. Finally, after all the experimentations, the optimum blend is obtained as a combination of diesel, biodiesel and diesel additive in certain proportions at 100 Percent load called as Blend number 6 (BL6), details of which are presented in Table 4.

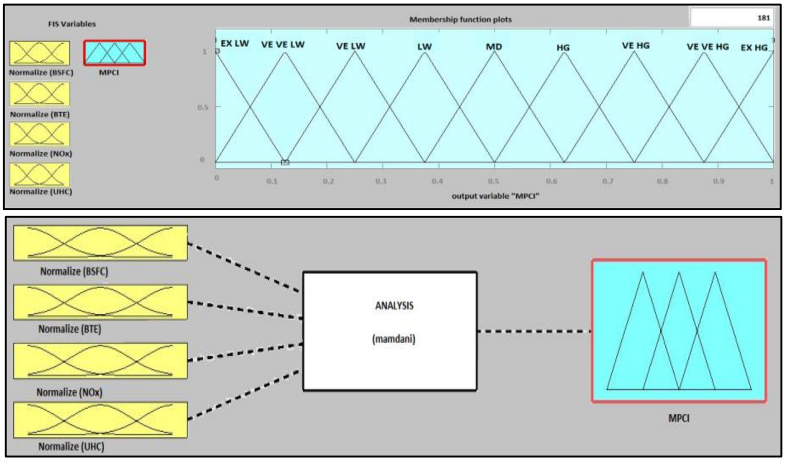


Figure 10: Membership functions (MPCI).

Table 4: Normalized value (Performance, emission and MPCI)

Sl. No	BSFC		BTE		NOx		UHC		MPCI
	SN Ratio	Normalize	SN Ratio	Normalize	SN Ratio	Normalize	SN Ratio	Normalize	
1	1.723	0	-6.020	0	-41.55	0.772	-58.80	0.000	0.17
2	1.830	0.012	-5.679	0.009	-44.44	0.625	-58.09	0.149	0.22
3	3.223	0.171	-1.618	0.119	-41.64	0.767	-55.95	0.204	0.41
4	2.733	0.115	-1.830	0.114	-41.97	0.750	-56.61	0.359	0.36
5	2.158	0.049	-4.152	0.050	-43.05	0.696	-57.52	0.894	0.26
6	2.498	0.088	-3.223	0.076	-37.06	1	-56.85	0.689	0.43
7	2.383	0.075	-3.478	0.069	-39.04	0.899	-57.00	0.515	0.36
8	2.047	0.037	-4.731	0.035	-41.11	0.794	-57.59	0.658	0.27
9	4.152	0.278	23.50	0.804	-46.75	0.508	-58.35	0.594	0.39
10	4.436	0.310	23.71	0.810	-48.16	0.437	-57.74	0.508	0.43
11	6.196	0.512	24.43	0.830	-47.46	0.472	-55.62	0.353	0.62
12	5.514	0.434	24.41	0.829	-47.53	0.468	-56.50	0.495	0.57
13	4.731	0.344	24.02	0.818	-47.81	0.455	-57.14	1.000	0.48
14	5.192	0.397	24.39	0.828	-46.39	0.527	56.62	0.898	0.57
15	5.036	0.379	24.14	0.822	-46.39	0.526	-56.83	0.651	0.52
16	4.582	0.327	23.85	0.814	-46.42	0.525	-57.23	0.852	0.47
17	5.679	0.452	26.85	0.896	-50.44	0.321	-58.22	0.785	0.44
18	5.848	0.472	26.89	0.897	-51.67	0.259	-57.63	0.607	0.47
19	7.535	0.665	28.30	0.935	-50.53	0.317	-55.46	0.000	0.68
20	6.935	0.596	28.25	0.934	-50.64	0.311	-56.39	0.149	0.60
21	6.196	0.512	27.47	0.912	-50.70	0.308	-57.04	0.204	0.51
22	6.744	0.574	28.14	0.931	-49.78	0.354	-56.44	0.359	0.62
23	6.375	0.532	27.69	0.918	-50.07	0.340	-56.58	0.894	0.57
24	6.020	0.491	27.42	0.911	-50.25	0.331	-57.07	0.689	0.52
25	6.744	0.574	29.01	0.954	-54.20	0.131	-58.00	0.515	0.47
26	6.935	0.596	29.20	0.960	-55.08	0.086	-57.40	0.658	0.49
27	8.635	0.791	29.56	0.969	-54.38	0.121	-55.32	0.594	0.71
28	8.404	0.764	29.53	0.969	-54.43	0.119	-56.12	0.508	0.64
29	7.744	0.689	29.31	0.963	-54.54	0.113	56.80	0.353	0.71
30	8.178	0.739	29.51	0.968	-53.47	0.168	-56.24	0.495	0.66
31	7.958	0.713	29.34	0.963	-53.57	0.162	-56.49	1.000	0.60
32	7.535	0.665	29.29	0.962	-53.97	0.142	-56.82	0.898	0.56
33	7.958	0.713	29.69	0.973	-56.45	0.016	-57.43	0.651	0.52
34	8.635	0.791	29.93	0.979	-56.78	0	-56.87	0.852	0.55
35	10.45	1	30.67	1	-56.46	0.016	-54.91	0.785	0.71
36	10.17	0.967	30.63	0.999	-56.63	0.007	-55.31	0.607	0.72
37	9.370	0.875	30.09	0.984	-56.76	0.001	-56.27	0.000	0.60
38	9.897	0.935	30.36	0.991	-56.16	0.031	-55.49	0.149	0.75
39	9.629	0.905	30.14	0.985	-56.40	0.019	-55.74	0.204	0.66
40	9.118	0.846	30.04	0.982	-56.43	0.018	-56.44	0.359	0.60

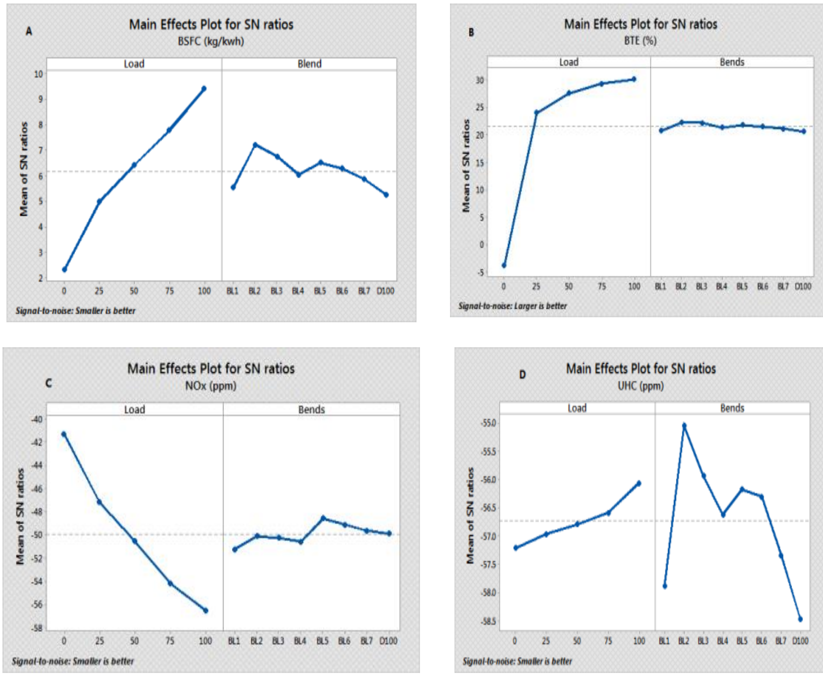


Figure 11: S/N response curve (A: BSFC, B: BTE, C: NOx, D: UHC).

Table 5: Fuzzy matrix (rule)

Sl.NO	BSFC	BTHE	UHC	NO_X	MPCI
1	LW	LW	LW	LW	EX LW
2	LW	LW	LW	MD	VE VE LW
3	LW	LW	MD	LW	VE VE LW
4	LW	LW	LW	HG	VE LW
5	LW	LW	HG	LW	VE LW
6	LW	LW	MD	MD	VE LW
7	LW	LW	MD	HG	LW
8	LW	LW	HG	MD	LW
9	LW	LW	HG	HG	MD
10	LW	MD	LW	LW	VE VE LW
11	LW	MD	MD	LW	VE LW
12	LW	MD	LW	MD	VE LW
13	LW	MD	MD	MD	LW
14	LW	MD	HG	LW	LW
15	LW	MD	LW	HG	LW
16	LW	MD	HG	MD	MD
17	LW	MD	MD	HG	MD
18	LW	MD	HG	HG	HG
19	LW	HG	LW	LW	VE LW
20	LW	HG	LW	MD	LW
21	LW	HG	MD	LW	LW
22	LW	HG	HG	LW	MD
23	LW	HG	LW	HG	MD
24	LW	HG	MD	MD	MD
25	LW	HG	MD	HG	HG
26	LW	HG	HG	MD	HG
27	LW	HG	HG	HG	VE HG
28	MD	LW	LW	LW	VE VE LW
29	MD	LW	LW	MD	VE LW
30	MD	LW	MD	LW	VE LW
31	MD	LW	LW	HG	LW
32	MD	LW	HG	LW	LW
33	MD	LW	MD	MD	LW
34	MD	LW	MD	HG	MD
35	MD	LW	HG	MD	MD
36	MD	LW	HG	HG	HG
37	MD	MD	LW	LW	VL
38	MD	MD	LW	MD	LW
39	MD	MD	MD	LW	LW
40	MD	MD	LW	HG	MD
41	MD	MD	HG	LW	MD
42	MD	MD	MD	MD	MD
43	MD	MD	MD	HG	HG

Sl.NO	BSFC	BTHE	UHC	NO_X	MPCI
44	MD	MD	HG	MD	HG
45	MD	MD	HG	HG	VE HG
46	MD	HG	LW	LW	LW
47	MD	HG	LW	MD	MD
48	MD	HG	MD	LW	MD
49	MD	HG	LW	HG	HG
50	MD	HG	HG	LW	HG
51	MD	HG	MD	MD	HG
52	MD	HG	MD	HG	VE HG
53	MD	HG	HG	MD	VE HG
54	MD	HG	HG	HG	VE VE HG
55	HG	LW	LW	LW	VE LW
56	HG	LW	LW	MD	LW
57	HG	LW	MD	LW	LW
58	HG	LW	LW	HG	MD
59	HG	LW	HG	LW	MD
60	HG	LW	MD	MD	MD
61	HG	LW	MD	HG	HG
62	HG	LW	HG	MD	HG
63	HG	LW	HG	HG	VH
64	HG	MD	LW	LW	LW
65	HG	MD	LW	MD	MD
66	HG	MD	MD	LW	MD
67	HG	MD	LW	HG	HG
68	HG	MD	HG	LW	HG
69	HG	MD	MD	MD	HG
70	HG	MD	MD	HG	VE HG
71	HG	MD	HG	MD	VE HG
72	HG	MD	HG	HG	VE VE HG
73	HG	HG	LW	LW	MD
74	HG	HG	LW	MD	HG
75	HG	HG	MD	LW	HG
76	HG	HG	LW	HG	VE HG
77	HG	HG	HG	LW	VE HG
78	HG	HG	MD	MD	VE HG
79	HG	HG	MD	HG	VE VE HG
80	HG	HG	HG	MD	VE VE HG
81	HG	HG	HG	HG	EX HG

Conclusions

Based on the experimental study to understand the potential of blended biofuels MIME and additives triacetin, 2-EHN on CI engine in terms of emission and performance and the same is validated using Taguchi –Fuzzy approach with the following conclusions:

- For every blend, BTE got increased with increasing the load. Among the blends, BL2 and BL3 possess BTE 12%, and 11% more than plain diesel in full load respectively.
- At maximum load, BSFC of blend 2, 3 and 5 are (25, 22.5, 20)% less than plain diesel.
- The NOx is observed to be (4, 2.1 and 3.6)% higher in case of the blend (2, 3, and 4) at higher load (100%) condition. But blend (5, 6 and 7) produced (3.3, 1 and 0.3) less NOx than D100.
- It is seen that BL2, BL3 and BL5 had lowermost UHC emission of 26%, 27% and 34% than pure diesel at 100% load.
- Afterwards, a model was designed using two input and one output parameters i.e fuel blend and load as output parameters and MPCI as output parameter using fuzzy rules. MPCI value of 0.75 is considered as the optimum value which is possessed by blend 5 resulting in higher emission control and performance.

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