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Application of TOPSIS Method for Multi-Characteristic Optimization of Vibration and Noise Characteristics of a Dual-Fuel CI Engine

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Abstract

The study focuses on optimizing vibration and noise characteristics in a dual-fuel compression ignition engine using CNG and Karanja biofuel blends. A hybrid optimization strategy using the Taguchi method and TOPSIS was employed to find the best compromise solution. The study used an experimental matrix with twenty-Seven experiments and four input parameters. The TOPSIS method was applied to solve a multi-objective optimization problem. The results showed that the TOPSIS outcome was valid with X -axis RMS velocity vibration at 7.49 mm/s and combustion noise at 93.9 dB, confirming model accuracy. This approach demonstrates a powerful framework for achieving multi-objective optimization in dual-fuel engines.

1. Introduction

The study explores the use of dual-fuel CI engines, particularly with gaseous fuels like CNG and biodiesel like Karanja oil methyl ester, as a solution to fossil fuel depletion and environmental degradation. However, the engine's noise and vibration levels may compromise comfort and structural integrity. The study uses advanced multi-criteria decision-making tools, such as the Taguchi method and TOPSIS, to identify optimal operating conditions that minimize vibration and combustion noise, addressing the complex trade-offs inherent in such systems. Trung et.al investigates the use of segmented grinding wheels for improved surface grinding efficiency. It focuses on optimizing surface roughness, vibrations (Ax, Ay, Az), and material removal rate (MRR). DIN 1.2379 steel work pieces and aluminum oxide grinding wheels with different groove numbers were used. Experiments were designed using the Taguchi L9 orthogonal array with four input parameters. [1] Nguyen et.al. studied used mutil-objective optimization for surface grinding of SAE420 steel using aluminum oxide grinding wheels with various grooves. The Taguchi method was used to design the experimental matrix, with input parameters including groove number, workpiece velocity, feed rate, and cutting depth. The DEAR technique was used to determine the minimum values of input parameters. The optimum values were 18 grooves, 15 m/min, 2 mm/stroke, and 0.005 mm. The results improved grinding surface quality and reduced vibrations, reducing cutting forces. [2] Sakthivel et.al. studied hybrid Multi Criteria Decision

Making (MCDM) technique for selecting the optimum fuel blend in fish oil biodiesel for internal combustion engines. The model, Analytical Network Process (ANP), is integrated with Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) to evaluate the performance, emission, and combustion parameters of a single cylinder, constant speed direct injection diesel engine. The resulting preference order is B20, which reduces NOx formation by 19% and decreases smoke without affecting engine performance or fuel economy. [3] Patil et.al studied to improve fuel properties using a novel multi-additive fuel blend, focusing on controlling engine emissions, particularly NOx, without compromising efficiency and fuel economy. Three additives, dimethyl carbonate, 2-ethylhexyl nitrate, and ethyl acetate, were identified for the blend. The Taguchi Design of Experiment method was used to identify sixteen test samples with different combinations. The optimized fuel blend, coded D8EH6E4, reduced NOx formation by an average of 19% and reduced smoke at higher load conditions without affecting engine performance [4] Raj et.al. investigated the machining characteristics of AISI D2 tool steel using an electrical discharge machining (EDM) process, replacing copper electrodes with carbon nano tube (CNT) fused electrodes. The study aims to improve machine ability factors like material removal rate, electrode wear rate, and surface finish, addressing issues like high electrode wear and poor dimensional and shape accuracy [5]. Huu et.al. proposed a multi-objective optimization solution for powder mixed electrical discharge machining using titanium powder. It uses Taguchi-AHP-Deng's method to solve multi-criteria decision making problems. The optimal material for workpiece is SKD11 die steel, electrode material is Gr, and electrode polarity should be positive. This study explores the optimization of vibration and noise characteristics of a CI engine running on compressed natural gas (CNG) and Karanja biofuel blends using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

2. Design of Experiment

2.1. Experimental Setup

A schematic of a single cylinder diesel engine and its relevant accessories shows in Fig. 1. The steady state engine tests were performed using an modified Kirloskar 244 Single cylinder, four strokes diesel engine to examine the effect of CNG concentration addition with biodiesel and diesel on engine performance and exhaust gas emissions. This engine consists of a single cylinder with direct injection to the combustion chamber and it is equipped with the external cooled EGR system. The Eddy current dynamometer was used to measure power of engine. An orifice plate equipped with monometer was used to measure the intake air flow rate into the engine. A nozzle of gas fuel (CNG) was also installed at the intake air pipe (between an orifice and air filter). Liquid fuels (diesel or biodiesel) from tanks it is injected into the diesel engine. [9,10,11] Figure 1 shows Actual View of Experimental Setup

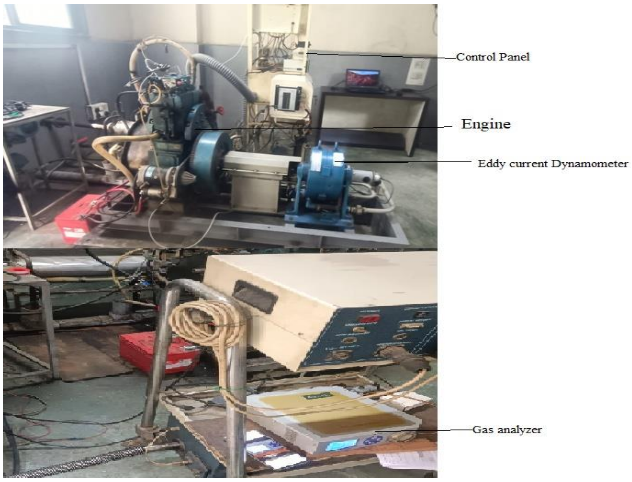

Figure 1 Actual View of Experimental Setup

2.2. Engine Specifications

Experimental work setup consists of 1 cylinder, 4 stroke, DI engine 3.73 kW as shown in fig.2, modified to operate CNG and Karanja biodiesel. The fuels tested included conventional diesel, CNG, and Karanja biodiesel blends ((D90KB10- CNG 0,2,4). The engine was equipped with vibration and noise sensors, and an emission analyzer. The vibrations that to be measured in X Axis Velocity RMS mm/s. This is in linear directions (In X-directions). Vibration signals can be analyzed in time domain by FFT (Fast Fourier Transform) Equipped with sensors to measure vibration, noise, and emission parameters. Water-cooled system to maintain consistent operating temperatures.

2.2.1. Vibration Measurement Method

An accelerometer (piezoelectric sensor) mounted on the engine block was used to measure engine vibrations. Data acquisition was performed using a vibration analyzer connected to a digital signal processing system. Vibrations were measured in terms of velocity m/s X directions, at 6 kg medium engine load and 1500 rpm engine run. Time domain analysis (Fast Fourier Transform) was performed to assess dominant vibration.

2.2.2. Noise Measurement Method

A precision sound level meter was positioned at a fixed distance of 1 meter from the engine to record combustion noise levels. The measurement was conducted following ISO 3746 standards for noise evaluation in internal combustion engines. The noise level was recorded in decibels (dB) under varying engine loads. Data was analyzed using spectral analysis to identify dominant noise frequencies.

2.3. Selection of an Orthogonal Array

To optimize the vibration, noise, and emission characteristics of a dual fuel compression ignition (CI) engine using CNG and Karanja biofuel blends, four critical control factors were selected: Fuel Fraction (CNG %), Compression Ratio, Injection Pressure, and Injection Timing. Each factor was studied at three levels, as shown in Table 1. Try to obtain the optimum level of input parameters i.e CNG fuel fraction rate with Karanja biodiesel (D90KB10- CNG 0,2,4 %), C.R., Injection pressure, IT BTDC (Injection timing) to minimize the vibration and noise of engine to improve the comfort to human being. Given that the experiment involves four factors each at three levels, the L_{27} orthogonal array (Taguchi method) was chosen for the design of experiments. Using the L_{27} design, 27 unique combinations of input parameters were generated to systematically analyze the effect of each parameter on the engine's performance. This approach ensures balanced and efficient experimentation while reducing the total number of tests compared to a full factorial design ($3^4 = 81$ experiments). Table 1 shows Four Input Controlled Parameters and 3 Levels [7,8]

Table 1 Four Input Controlled Parameters and 3 Levels

Controlled Parameters	Level - 1	Level- 2	Level- 3
Fuel Fraction CNG % (FF)	0	2	4
Compression Ratio (CR)	16 :1	17 :1	18 :1
Injection pressure (IP)	400 bar	500 bar	600 bar
Injection Timing BTDC deg. (IT)	19 deg.	23 deg.	27 deg.

Try to obtain the optimum level of input parameters i.e CNG fuel fraction rate with Karanja biodiesel (D90KB10- CNG 0,2,4 %), C.R., Injection pressure, IT BTDC (Injection timing) to minimize the vibration and noise of engine to improve the comfort to human being. Given that the experiment involves four factors each at three levels, the L_{27} orthogonal array (Taguchi method) was chosen for the design of experiments. Using the L_{27} design, 27 unique combinations of input parameters were generated to systematically analyze the effect of each parameter on the engine's performance. This approach ensures balanced and efficient experimentation while reducing the total number of tests compared to a full factorial design ($3^4 = 81$ experiments).[7,8]

2.4. Design of Experiments (DOE)

After choosing the orthogonal array, the experiments are carried out using the level combinations. The execution of all the experiments is required. L27 orthogonal array was used since there were four components and three levels in this investigation [7]. This structured DOE approach using the L_{27} array not only reduces the number of experimental runs significantly but also enables effective evaluation of the influence of each factor on the responses. [17,18]

3. Analysis of Result

Minitab 19 tool is employed for data analysis. Two response parameters from the result in table 3 are selected for study in order to determine the best combination that can produce a Vibration X -axis Velocity RMS mm/and Combustion Noise dB. Twenty-seven experiments were carried out in accordance with the L27 orthogonal array, with the findings for Vibration at X axis direction (Top side) and Combustion noise displayed in table 3. Table 2 shows Experimental Matrix Based on L_{27}

Orthogonal Array generated to systematically analyze the effect

Table 2 Experimental Matrix Based on L_{27} Orthogonal Array

Exp. No	FF (%)	CR	IP (bar)	IT (°bTDC)
1	0	16	400	19
2	0	16	400	23
3	0	16	400	27
4	2	17	500	19
5	2	17	500	23
6	2	17	500	27
7	4	18	600	19
8	4	18	600	23
9	4	18	600	27
10	0	17	600	19
11	0	17	600	23
12	0	17	600	27
13	2	18	400	19
14	2	18	400	23
15	2	18	400	27
16	4	16	500	19
17	4	16	500	23
18	4	16	500	27
19	0	18	500	19
20	0	18	500	23
21	0	18	500	27
22	2	16	600	19
23	2	16	600	23
24	2	16	600	27
25	4	17	400	19
26	4	17	400	23
27	4	17	400	27

Table 3 Result Table

Exp. No	FF (%)	CR	IP (bar)	IT (°bTDC)	Vibration X -axis Velocity RMS mm/s	Combustion Noise dB
1	0	16	400	19	8.25	97.7
2	0	16	400	23	9.49	98.6
3	0	16	400	27	9.58	99.2
4	2	17	500	19	9.22	98.1
5	2	17	500	23	11.3	99.1
6	2	17	500	27	14.2	99.4
7	4	18	600	19	8.58	96.2
8	4	18	600	23	8.75	97.1
9	4	18	600	27	9.76	94.7
10	0	17	600	19	9.63	97.9
11	0	17	600	23	10.9	99.3
12	0	17	600	27	16.9	100.9
13	2	18	400	19	9.19	96.6
14	2	18	400	23	10.1	97.8
15	2	18	400	27	11.6	98.4

16	4	16	500	19	7.49	93.9
17	4	16	500	23	8.05	95
18	4	16	500	27	8.02	94.3
19	0	18	500	19	10.2	97.3
20	0	18	500	23	11.4	99.1
21	0	18	500	27	14.5	99.6
22	2	16	600	19	8.92	98.9
23	2	16	600	23	11.2	100.9
24	2	16	600	27	9.87	100.9
25	4	17	400	19	8.19	93.9
26	4	17	400	23	8.9	96.5
27	4	17	400	27	8.76	96.1

TOPSIS is a multi-criteria decision analysis technique that uses weights, normalizes scores, and calculates the geometric distance between alternatives to find the ideal solution. This compensatory aggregation method compares a set of alternatives, assumed to be monotonically growing or decreasing, comparing the best score for each criterion.

4. Optimization Using Technique for Order of Preference (TOPSIS)

TOPSIS identifies the best alternative by evaluating the geometric distance of each option from an ideal (best) and a negative-ideal (worst) solution. This compensatory aggregation method compares a set of alternatives, assumed to be monotonically growing or decreasing, comparing the best score for each criterion. [8]

The steps involved:

- Normalization of vibration and noise values
- Weighting of criteria (equal importance)
- Calculation of Si+ and Si− (distance to ideal and negative-ideal solutions)
- Determination of performance index (Pi)
- Ranking based on Pi values

The normalized decision matrix for the provided data is shown in Table 4. Table 6 illustrates the Weighted Decision matrix, respective Euclidian distances, degree of closeness, and ranks for a set of input parameters whereas Table 5 displays the weighting applied to each output response variable. These are all taken from an excel spreadsheet that was created. The normalized decision matrix has been formed as shown in Table 4. Table 4 shows Normalized Decision Matrix

Table 4 Normalized Decision Matrix

Test	Experimental Result		Normalized Output	
Exp. No	Vibration X axis Velocity RMS mm/s	Combustion Noise dB	Vibration X axis Velocity RMS mm/s	Combustion Noise dB
1	8.25	97.7	0.1537	0.0768
2	9.49	98.6	0.1768	0.0884
3	9.58	99.2	0.1784	0.0892
4	9.22	98.1	0.1717	0.0859
5	11.3	99.1	0.2105	0.1052
6	14.2	99.4	0.2645	0.1322
7	8.58	96.2	0.1598	0.0799
8	8.75	97.1	0.1630	0.0815
9	9.76	94.7	0.1818	0.0909
10	9.63	97.9	0.1794	0.0897
11	10.9	99.3	0.2030	0.1015
12	16.9	100.9	0.3148	0.1574
13	9.19	96.6	0.1712	0.0856
14	10.1	97.8	0.1881	0.0941

15	11.6	98.4	0.2160	0.1080
16	7.49	93.9	0.1395	0.0698
17	8.05	95	0.1499	0.0750
18	8.02	94.3	0.1494	0.0747
19	10.2	97.3	0.1900	0.0950
20	11.4	99.1	0.2123	0.1062
21	14.5	99.6	0.2701	0.1350
22	8.92	98.9	0.1661	0.0831
23	11.2	100.9	0.2086	0.1043
24	9.87	100.9	0.1838	0.0919
25	8.19	93.9	0.1525	0.0763
26	8.9	96.5	0.1658	0.0829
27	8.76	96.1	0.1632	0.0816

Table 5 Considered Weightage of Output Response

Output Response	Vibration X axis Velocity RMS mm/s	Combustion Noise dB
Weightage	0.5	0.5

Table 6 Weighted Normalized Decision Matrix, Euclidian Distance & Relative Closeness

	Weighted Normalized Output					
Exp. No	**Vibration x- axis Velocity RMS mm/s**	**Combustion Noise dB**	**Si+**	**Si-**	**Pi**	**Rank**
1	0.0768	0.0962	0.0077	0.0806	0.9123	3
2	0.0884	0.0971	0.0188	0.0692	0.7866	13
3	0.0892	0.0977	0.0195	0.0684	0.7778	14
4	0.0859	0.0966	0.0163	0.0716	0.8142	12
5	0.1052	0.0976	0.0355	0.0524	0.5960	22
6	0.1322	0.0979	0.0625	0.0257	0.2915	25
7	0.0799	0.0947	0.0112	0.0775	0.8742	6
8	0.0815	0.0956	0.0123	0.0760	0.8605	7
9	0.0909	0.0933	0.0220	0.0665	0.7514	16
10	0.0897	0.0964	0.0201	0.0678	0.7710	15
11	0.1015	0.0978	0.0318	0.0561	0.6384	20
12	0.1574	0.0994	0.0876	0.0069	0.0729	27
13	0.0856	0.0951	0.0164	0.0718	0.8143	11
14	0.0941	0.0963	0.0245	0.0634	0.7214	18
15	0.1080	0.0969	0.0384	0.0496	0.5637	24
16	0.0698	0.0925	0.0069	0.0876	0.9271	1
17	0.0750	0.0936	0.0078	0.0824	0.9135	2
18	0.0747	0.0929	0.0082	0.0827	0.9102	4
19	0.0950	0.0958	0.0255	0.0625	0.7103	19
20	0.1062	0.0976	0.0365	0.0515	0.5854	23
21	0.1350	0.0981	0.0653	0.0230	0.2609	26
22	0.0831	0.0974	0.0135	0.0745	0.8469	9
23	0.1043	0.0994	0.0345	0.0535	0.6077	21
24	0.0919	0.0994	0.0222	0.0658	0.7481	17
25	0.0763	0.0925	0.0095	0.0811	0.8953	5
26	0.0829	0.0950	0.0138	0.0745	0.8435	10

27	0.0816	0.0946	0.0127	0.0758	0.8562	8

The closest and farthest points from the ideal solutions, or the Euclidian distance (S+&S-), are determined. The Pi value, or degree of proximity to the best solution, is calculated from these Euclidean distances, and the highest Pi value is indicated as the first ranking, while the lowest Pi value is marked as the final rank or the 27th rank. Table 7 lists the Pi values, Euclidian distances, Weighted Normalized Decision Matrix, and the corresponding rank assigned to each set of input parameters based on the Pi values. Table 5 shows Considered Weightage of Output Response Table 6 shows Weighted Normalized Decision Matrix, Euclidian Distance & Relative Closeness

Table 7 **Summarized TOPSIS Table Ranking the Set of Input Parameters**

Exp. No	FF %	CR	IP (bar)	IT (°bT DC)	Vibration x-axis RMS mm/s	Combustion Noise dB	Si+	Si-	Pi	Rank
1	0	16	400	19	8.25	97.7	0.0077	0.0806	0.9123	3
2	0	16	400	23	9.49	98.6	0.0188	0.0692	0.7866	13
3	0	16	400	27	9.58	99.2	0.0195	0.0684	0.7778	14
4	2	17	500	19	9.22	98.1	0.0163	0.0716	0.8142	12
5	2	17	500	23	11.3	99.1	0.0355	0.0524	0.5960	22
6	2	17	500	27	14.2	99.4	0.0625	0.0257	0.2915	25
7	4	18	600	19	8.58	96.2	0.0112	0.0775	0.8742	6
8	4	18	600	23	8.75	97.1	0.0123	0.0760	0.8605	7
9	4	18	600	27	9.76	94.7	0.0220	0.0665	0.7514	16
10	0	17	600	19	9.63	97.9	0.0201	0.0678	0.7710	15
11	0	17	600	23	10.9	99.3	0.0318	0.0561	0.6384	20
12	0	17	600	27	16.9	100.9	0.0876	0.0069	0.0729	27
13	2	18	400	19	9.19	96.6	0.0164	0.0718	0.8143	11
14	2	18	400	23	10.1	97.8	0.0245	0.0634	0.7214	18
15	2	18	400	27	11.6	98.4	0.0384	0.0496	0.5637	24
16	4	16	500	19	7.49	93.9	0.0069	0.0876	0.9271	1
17	4	16	500	23	8.05	95	0.0078	0.0824	0.9135	2
18	4	16	500	27	8.02	94.3	0.0082	0.0827	0.9102	4
19	0	18	500	19	10.2	97.3	0.0255	0.0625	0.7103	19
20	0	18	500	23	11.4	99.1	0.0365	0.0515	0.5854	23
21	0	18	500	27	14.5	99.6	0.0653	0.0230	0.2609	26
22	2	16	600	19	8.92	98.9	0.0135	0.0745	0.8469	9
23	2	16	600	23	11.2	100.9	0.0345	0.0535	0.6077	21
24	2	16	600	27	9.87	100.9	0.0222	0.0658	0.7481	17
25	4	17	400	19	8.19	93.9	0.0095	0.0811	0.8953	5
26	4	17	400	23	8.9	96.5	0.0138	0.0745	0.8435	10
27	4	17	400	27	8.76	96.1	0.0127	0.0758	0.8562	8

From Table 7, Based on the relative closeness, we understand that Exp. 14 shows the best set of input parameters while Exp. 12 shows the worst results. The optimal input parameters for the combined EDM machining are shown in Table 8.

Table 8 The Optimized Set of Input Parameters (Weightage 0.5-0.5)

Fuel Fraction CNG % (FF)	Compression Ratio (CR)	Injection pressure (IP) (bar)	Injection Timing (IT) (°bTDC)
4	16	500	19

Confirmation Test:

The best configuration (Test 16) corresponds to FF = 4, CR = 16, IP = 500 bar, IT = 19° BTDC, producing lowest vibration (7.49 mm/s) and lowest noise (93.9 dB) among all tests.A consistent trend observed was that lower injection timing and moderate fuel fraction improved combustion smoothness, leading to reduced noise and vibration. Tests with higher injection timing and pressure (e.g., IT = 27°, IP = 600 bar) often exhibited higher noise levels, likely due to more aggressive combustion phasing.

Conclusion

Fuel Fraction % is the most influential factor in reducing X-Axis Velocity RMS. Increasing the Fuel fraction tends to reduce combustion noise levels. The diesel engine's output parameters have been modified for the dual fuel of Karanja biodiesel and CNG This study successfully applied the TOPSIS approach to optimize vibration and noise characteristics in a dual-fuel CI engine running on CNG and Karanja biodiesel blends. The most favorable configuration was found to be FF = 4, CR = 16, IP = 500 bar, and IT = 19° BTDC, yielding minimal vibration and noise levels. Vibration and noise characteristics are heavily influenced by injection parameters and CNG blending ratio. The Taguchi-TOPSIS hybrid approach provides a robust and reliable methodology for multi-objective engine optimization.

References

[1]. Trung, D.D., Thien, N.V. and Nguyen, N.T., 2021. Application of TOPSIS method in multi-objective optimization of the grinding process using segmented grinding wheel. Tribology in industry, 43(1), p.12.

[2]. Nguyen, N.T., Tien, D.H. and Le Dang, H., 2021. A research on multi-objective optimization of the grinding process using segmented grinding wheel by Taguchi-Dear method. EUREKA: Physics and Engineering, (1), pp.67-77. https:// doi.org/ 10.21303/2461-4262.2021.001612

[3]. Sakthivel, G. and Ilangkumaran, M., 2015. A hybrid multi-criteria decision making approach of ANP and TOPSIS to evaluate the optimum fuel blend in IC engine. International Journal of Decision Support Systems, 1(3), pp.268-293. https:// doi.org/ 10.1504/IJDSS.2015.070170

[4]. Patil, A.R., Kakati, D., Singh, B., Rosen, M.A., Patil, R., Javanjal, V., Sonawane, C., Panchal, H., Kumar, A., Siddiqui, M.I.H. and Sadasivuni, K.K., 2024. Experimental investigation of multi-additive fuel blend and its optimization for CI engine performance and emissions by the hybrid Taguchi-TOPSIS technique. Case Studies in Thermal Engineering, 53, p.103703. https://doi.org/10.1016/j.csite.2023.103703

[5]. Raj, S.O.N. and Prabhu, S., 2017. Analysis of multi objective optimisation using TOPSIS method in EDM process with CNT infused copper electrode. International Journal of Machining and Machinability of Materials, 19(1), pp.76-94.

[6]. Huu, P.N., 2020. Multi-objective optimization in titanium powder mixed electrical discharge machining process parameters for die steels. Alexandria engineering journal, 59(6), pp.4063-4079. https://doi.org/10.1016/j.aej.2020.07.012

[7]. Mane, A. and Jadhav, P.V., 2023. Process parameter improvement for NITi's electrical discharge machining (EDM) process utilizing the TOPSIS approach. Research on Engineering Structures and Materials, 9, pp.83-94. http:// dx.doi. org/ 10.17515/resm2022.510ma0826

[8]. Mane, A.B. and Jadhav, P., 2021. Optimization of response parameters of

electrical discharge machine using shape memory alloy. International Journal of Mechanical Engineering, 6(3), pp.86-91.
[9]. Kumbhar, V.S., Shahare, A. and Awari, G.K., 2021, August. Review on reactivity controlled compression ignition engines: an approach for BSVI emission norms. In IOP Conference Series: Materials Science and Engineering (Vol. 1170, No. 1, p. 012011). IOP Publishing.
[10]. Kumbhar, V.S., Shahare, A.S. and Awari, G.K., 2021, November. Influence of injection pressure on performance and emission characteristics of single cylinder RCCI engine fuelled with ethanol gasoline and diesel biodiesel blends. In Journal of Physics: Conference Series (Vol. 2070, No. 1, p. 012160). IOP Publishing.
[11]. Kumbhar, V.S., Shahare, A.S. and Awari, G.K., 2022. An experimental investigation on gasoline diesel and biofuelled RCCI combustion and its comparison with the conventional diesel combustion. Materials Today: Proceedings, 59, pp.525-533.
[12]. Hwang, C. L., & Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. Springer.
[13]. Montgomery, D. C. (2017). Design and Analysis of Experiments. Wiley.
[14]. Anand, K., & Ramesh, A. (2006). Use of CNG in dual fuel CI engines: A review. SAE Technical Paper.
[15]. Rao, R. V. (2007). Decision Making in the Manufacturing Environment. Springer.
[16]. Murugan, S., et al. (2008). The use of tyre pyrolysis oil in diesel engines. Fuel, 87(7), 1560–1566.
[17]. Jadhav Sangram D. &Tandale Madhukar S., “Part load and full load multi-objective performance optimization of a single-cylinder diesel engine operating on Mangiferaindica biodiesel as biofuel”, Biofuels (T & F), 2016, pp. 1-16.
[18]. Kadam, D. V., & Jadhav, S. D. (2017). Optimization of Vibration, Performance and Emission of CI Engine Operated on Simarouba Biodiesel Using Taguchi and Multiple Regression Analysis (No. 2017-01-2137). SAE Technical Paper.