International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Performance and Emission Characteristics of Hongebiodiesel Fueled CI Engine by using Taguchi Method

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Abstract: ***The process parameters optimization is the essential step in Taguchi approach, which utilizes orthogonal array for maximizing the effect of controllable parameters and for minimizing the effect of uncontrollable process parameters. This study presents optimal parameters that influences on the BP, BSFC, CO, HC, NOx using Taguchi method. The 3 level 4 factor design has been considered they are Torque, Injection pressure, Timing, Fuel. The L9 orthogonal array is employed and signal-noise ratio (S/N ratio). Larger is better type is employed for BP and smaller is better type has been employed for BSFC, CO, HC, NOx and analysis of variance, (ANOVA) are considered for identifying the best optimum conditions.***

Keywords: BP, BSFC, CO, HC, NOx, Torque, Injection pressure, Fuel, Timing and ANOVA, Taguchi approach

1. Introduction

Performance parameters and the emission characteristics of the CI engine has been considered and here 3 level 4 factors design has been considered in the taguchi analysis. Taguchi analysis has made to know which factors influence more on the emission and the performance parameters. Anova is made to know about the error in the performance. Taguchi has used to make the calculations simpler for more parameters.

Taguchi Experiment: Design and Analysis

The simulation tests were carried out as per the standard L9 orthogonal array. The various factors taken for the calculation were Torque, Injection pressure, Fuel and Timings. Each factor was provided with three levels as displayed in Table 1.

Table 1: Factors and level for Emission and Combustion characteristics

Factors	Level 1	Level 2	Level 3
Torque	6.5	13	19.5
Injection pressure	200	250	300
Fuel	0*	10**	20***
Timings	16 (RTD)	21 (STD)	26 (ADV)

*= Neat diesel
**= 10% biodiesel
***= 20% biodiesel

Table 2: Orthogonal array of Taguchi and Signal to noise ratio for BP

Torque	Injection pressure	Fuel	Timing	BP	SNRA1
6.5	200	0	16	0.978	-0.19322
6.5	250	10	21	0.908	-0.83828
6.5	300	20	26	0.978	-0.19322
13.0	200	10	26	1.871	5.44148
13.0	250	20	16	1.943	5.76946
13.0	300	0	21	1.924	5.68410
19.5	**200**	**20**	**21**	**2.841**	**9.06942**
19.5	250	0	26	2.839	9.06331
19.5	300	10	16	2.692	8.60150

The high S/N ratio gives the optimal quality and has low variance using the MINITAB software. Larger is better type has chosen and the similar response was used for signal to noise ratio. It shows that for higher torque value the SN ratio is higher i.e for higher torque the value of BP is higher.

The S/N ratio is analyzed by using the equation

$$S/N = -10log_{10}(\frac{1}{n}\sum 1/y^2)$$

Result and discussion for BP

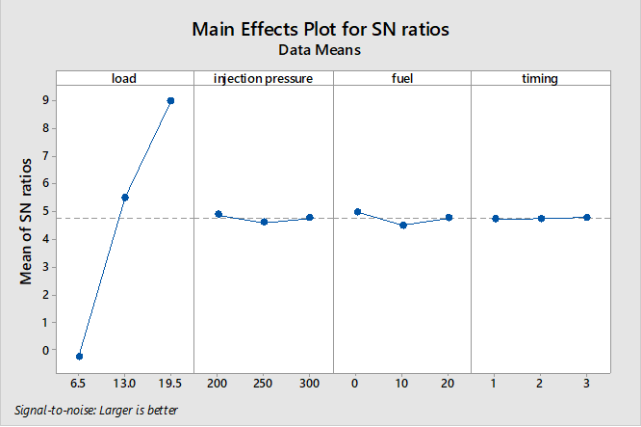


Figure 1: Effect plot for SN ratios on BP

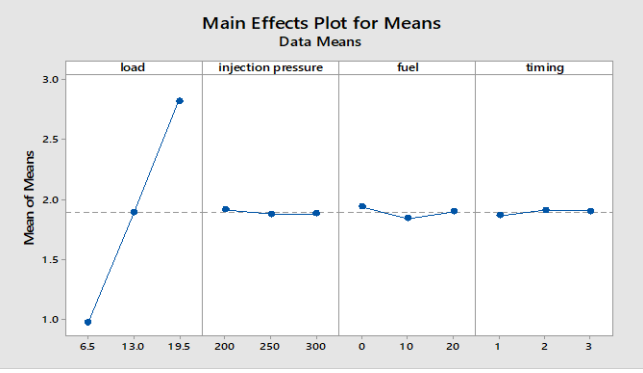


Figure 2: Effect plot for Means on BP

Table 3: Response for BP

Response Table for Signal to Noise Ratios
Larger is better

Level	Torque	Injection pressure	Fuel	Time
1	0.3438	4.7726	1.9425	3.8656
2	3.7370	3.6506	3.5413	2.7437
3	7.0369	2.0069	4.9463	3.8207
Delta	7.3807	2.7657	3.0038	1.1219
Rank	1	3	2	4
Response Table for Means				
Level	Torque	Injection pressure	Fuel	Time
1	0.9620	1.8967	1.3260	1.6403
2	1.6047	1.6170	1.5930	1.5830
3	2.2803	1.3333	1.9280	1.6237
Delta	1.3183	.5633	0.6020	0.0573
Rank	1	3	2	4

Analysis of variance (ANOVA)

It can observed from the ANOVA analysis that the torque(71.74%) , injection pressure(13.096%) and fuel(15.016%) have the influence on BP. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result. The Torque (71.74%) and the fuel (15.016%) has the greatest influence on the BP while the injection pressure has the least influence on the BP.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Torque	2	2.60755	1.30377	499.66	0.02	71.74
Injection pressure	2	0.47602	0.23801	91.22	0.011	13.096
Fuel	2	0.54592	0.27296	104.61	0.009	15.016
Error	2	0.00522	0.00261			0.1436
Total	8	3.63471				100

It can observed from the ANOVA analysis that the torque, injection pressure and fuel have the influence on B. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result. The Torque and the injection pressure has the greatest influence on the BP while the fuel has the least influence on the BP.

Table 4: Orthogonal array of Taguchi and Signal to noise ratio for BSFC

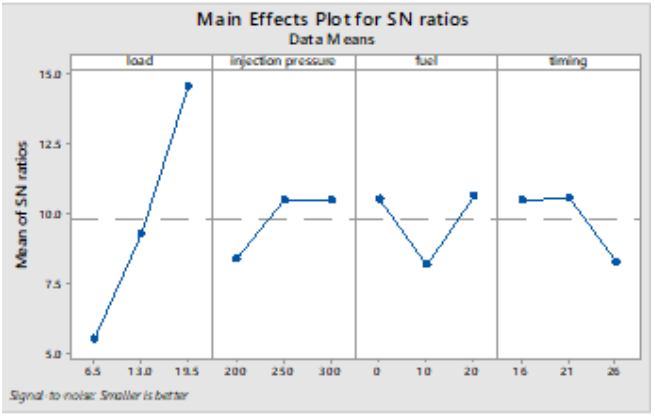
Torque	Injection pressure	Fuel	Timing	BSFC	SNRA1
6.5	200	0	16	0.5265	5.5720
6.5	250	10	21	0.5339	5.4508
6.5	300	20	26	0.5261	5.5786
13.0	**200**	**10**	**26**	**0.5751**	**4.8051**
13.0	250	20	16	0.2649	11.5384
13.0	300	0	21	0.2653	11.5253
19.5	200	20	21	0.1812	14.8368
19.5	250	0	26	0.1883	14.5030
19.5	300	10	16	0.1912	14.3702

The high S/N ratio gives the optimal quality and has low variance using the MINITAB software. Smaller is better type has chosen and the similar response was used for signal to noise ratio. It shows that for 13 torque value the SN ratio is smaller i.e for 13 torque the value of BSFC is lower.

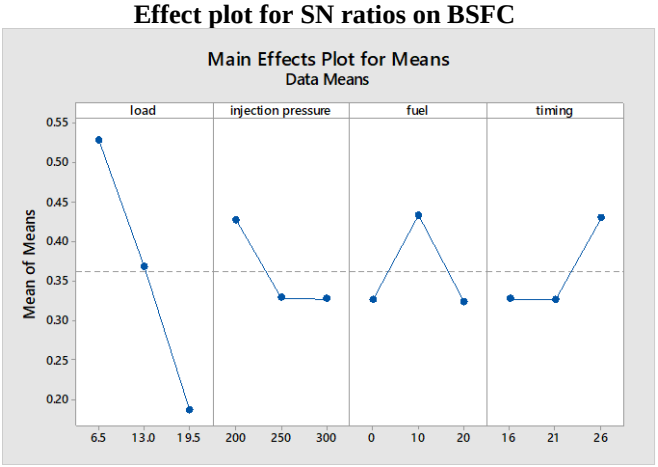
The S/N ratio is analyzed by using the equation

$$S/N = -10log_{10}(\frac{1}{n}\sum 1/y^2)$$

Result and discussion for BSFC



Effect plot for SN ratios on BSFC



Effect plot for means on BSFC

Response for BSFC

Response Table for Signal to Noise Ratios Smaller is better				
Level	Torque	Injection pressure	Fuel	Timing
1	5.534	8.405	10.533	10.494
2	9.290	10.497	8.209	10.604
3	14.570	10.491	10.651	8.296
Delta	9.036	2.093	2.443	2.309
Rank	1	4	2	3
Response for Means				
Level	Torque	Injection pressure	Fuel	Timing
1	0.5288	0.4276	0.3267	0.3275
2	0.3684	0.3290	0.4334	0.3268
3	0.1869	0.3275	0.3241	0.4298
Delta	0.3419	0.1001	0.1093	0.1030
Rank	1	4	2	3

Analysis of variance (ANOVA):

ANOVA is a statistically built, objective judgement-making tool for identifying any dis similarities in the average performance of groups of items that were verified. ANOVA aids in analyzing the importance of all-required factors and their interactions by matching the average square against an Estimate of the experimental errors at specific confidence levels. This analysis was conducted for a level of significance of 5% (that is the level of confidence of 95%). Table 4 displays the ANOVA

Results

Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Torque	2	0.17560	0.08780	8.21	0.019	73.2399
Error	6	0.06416	0.01067			26.76
Total	8	0.23976				100

It can observed from the ANOVA analysis that only torque (73.2999%) have the influence on BSFC and the other factors have negligible impact. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result.

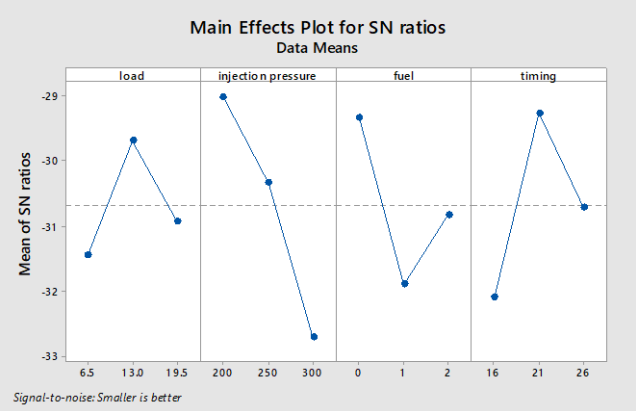
Orthogonal array of Taguchi and Signal to noise ratio for CO:

Torque	Injection pressure	Fuel	Timing	CO	SNRA1
6.5	200	0	16	31	-29.8272
6.5	250	1	21	35	-30.8814
6.5	300	2	26	48	-33.6248
13.0	200	1	26	29	-29.2480
13.0	250	2	16	35	-30.8814
13.0	300	0	21	28	-28.9432
19.5	200	2	21	25	-27.9588
19.5	250	0	26	29	-29.2480
19.5	**300**	**1**	**16**	**60**	**-35.5630**

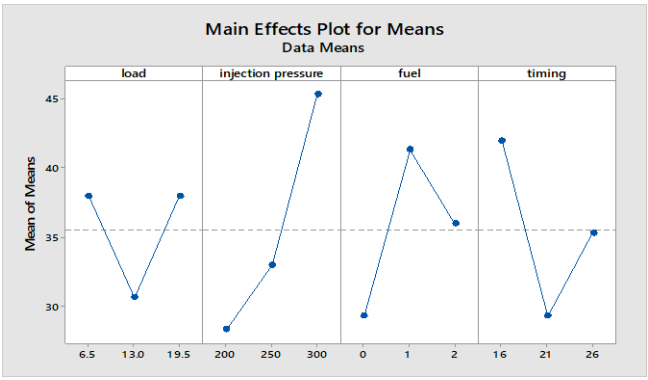
The high S/N ratio gives the optimal quality and has low variance using the MINITAB software. Smaller is better type has chosen and the similar response was used for signal to noise ratio. It shows that for higher torque value the SN ratio is smaller i.e for higher torque the value of CO is lower.

The S/N ratio is analyzed by using the equation

$$S/N = -10 log_{10}(\frac{1}{n}\sum 1/y^2)$$



Effect plot for SN ratios on CO



Effect plot for means on CO

Response for CO

Response Table for Signal to Noise Ratio Smaller is Better				
Level	Torque	Injection pressure	Fuel	Timing
1	-31.44	-29.01	-29.34	-32.09
2	-29.69	-30.34	-31.90	-29.26
3	-30.92	-32.71	-30.82	-30.71
Delta	1.75	3.70	2.56	2.83
Rank	4	1	3	2
Response Table For Means				
Level	Torque	Injection Pressure	Fuel	Timing
1	38.00	28.33	29.33	42.00
2	30.67	33.00	41.33	29.33
3	38.00	45.33	36.00	35.33
Delta	7.33	17.00	12.00	12.67
Rank	4	1	3	2

Analysis of Variance (ANOVA)

ANOVA is a statistically built, objective judgement-making tool for identifying any dis similarities in the average performance of groups of items that were verified. ANOVA aids in analyzing the importance of all-required factors and their interactions by matching the average square against an Estimate of the experimental errors at specific confidence levels. This analysis was conducted for a level of significance of 5% (that is the level of confidence of 95%). Table 4 displays the ANOVA

Results

Analysis Of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Injection Pressure	2	462.9	231.44	2.46	0.166	45.02
Error	6	565.3	94.22			54.979
Total	8	1028.2				100

It can be observed from the ANOVA analysis that only the injection pressure (45.02%) have the influence on CO. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result. The injection pressure has the greatest influence on the CO.

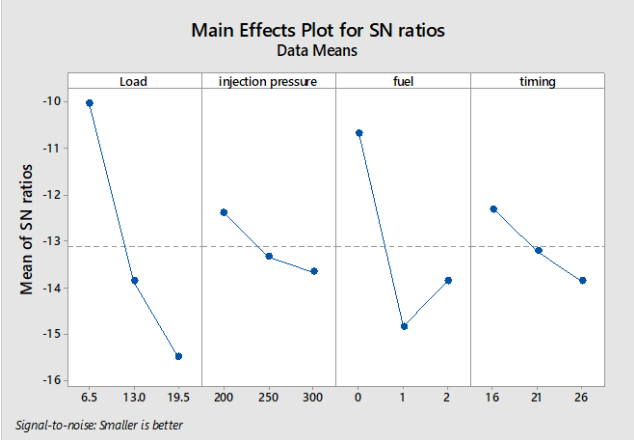
Orthogonal array (L9) of Taguchi and signal to noise ratio for HC

Torque	Injection pressure	Fuel	Timing	HC	SNRA1
6.5	200	0	16	2	-6.0206
6.5	250	1	21	4	-12.0412
6.5	300	2	26	4	-12.0412
13.0	200	1	26	6	-15.5630
13.0	250	2	16	5	-13.9794
13.0	300	0	21	4	-12.0412
19.5	200	2	21	6	-15.5630
19.5	250	0	26	5	-13.9794
19.5	**300**	**1**	**16**	**7**	**-16.9020**

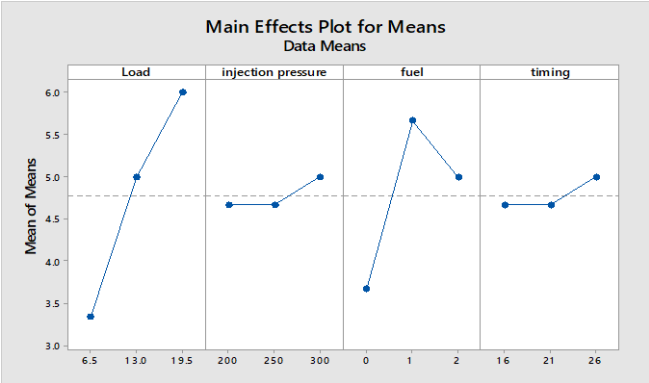
The high S/N ratio gives the optimal quality and has low variance using the MINITAB software. Smaller is better type has chosen and the similar response was used for signal to noise ratio. It shows that for higher torque value the SN ratio is higher i.e for higher torque the value of HC is lower.

The S/N ratio is analyzed by using the equation

$$S/N = -10 log_{10}(\frac{1}{n}\sum 1/y^2)$$



Effect plot for SN ratios on HC



Effect plot for means on HC

Response for HC

Response Table For Signal to Noise Ratio Smaller is better				
Level	Torque	Injection Pressure	Fuel	Timing
1	-10.03	-12.38	-10.68	-12.30
2	-13.86	-13.33	-14.84	-13.22
3	-15.48	-13.66	-13.86	-13.56
Delta	5.45	1.28	4.15	1.56
Rank	1	4	2	3

Response Table for Means				
Level	Torque	Injection pressure	Fuel	Timing
1	3.333	4.667	3.667	4.667
2	5.000	4.667	5.667	4.667
3	6.000	5.000	5.000	5.000
Delta	2.667	0.333	2.000	0.333
Rank	1	4	2	3

Analysis Of Variance (ANOVA)

ANOVA is a statistically built, objective judgement-making tool for identifying any dis similarities in the average performance of groups of items that were verified. ANOVA aids in analyzing the importance of all-required factors and their interactions by matching the average square against an Estimate of the experimental errors at specific confidence levels. This analysis was conducted for a level of significance of 5% (that is the level of confidence of 95%). Table 4 displays the ANOVA

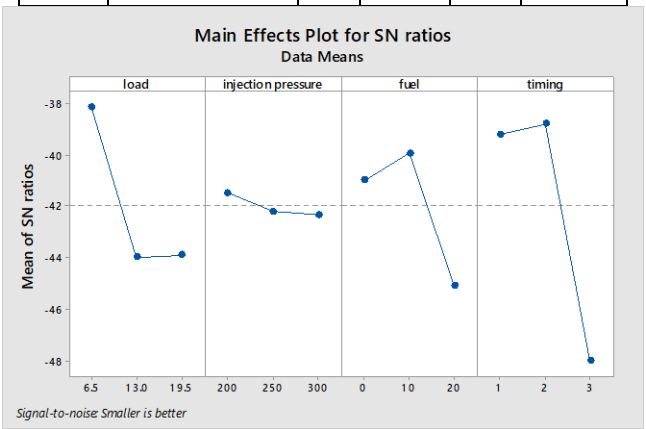
Results

Analysis Of Variance						
Source	DF	Seq SS	Seq MS	F-Value	P-Value	% Contribution
Torque	2	10.8889	5.444	49.00	0.002	62.025
Fuel	2	6.222	3.111	28.00	0.004	35.44
Error	4	0.4444	0.111			2.596
Total	8	17.5556				100

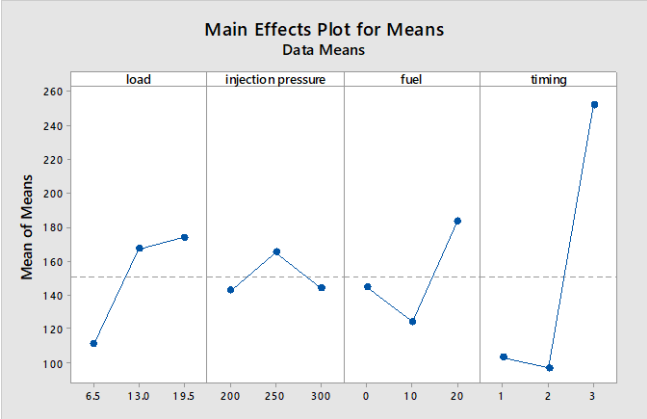
It can observed from the ANOVA analysis that the torque (62.025%) has the more influence on HC. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result. The torque(62.025%) and Fuel (35.44%) has the greatest influence on the HC and other factors have negligible influence on HC.

Orthogonal array (L9) of Taguchi and signal to noise ratio for NOx

Torque	Injection pressure	Fuel	Timing	NOX	SNRA1
6.5	200	0	1	49	-33.8039
6.5	250	10	2	45	-33.0643
6.5	**300**	**20**	**3**	**239**	**-47.5680**
13.0	200	10	3	234	-47.3843
13.0	250	20	1	167	-44.4543
13.0	300	0	2	101	-40.0864
19.5	200	20	2	145	-43.2274
19.5	250	0	3	284	-49.0664
19.5	300	10	1	93	-39.3697



Effect plot for SN ratios on NOx



Effect plot for means on NOx

The high S/N ratio gives the optimal quality and has low variance using the MINITAB software. Smaller is better type has chosen and the similar response was used for signal to noise ratio. It shows that for lower torque value the SN ratio is higher i.e for lower torque the value of NOx is lower.

The S/N ratio is analyzed by using the equation

$$S/N = -10 log_{10}\left(\frac{1}{n}\sum 1/y^2\right)$$

Response for NOx

Response Table for Signal to Noise Ratios Smaller is better				
Level	Torque	Injection pressure	Fuel	Timing
1	-38.15	-41.47	-40.99	-39.21
2	-43.98	-42.19	-39.94	-38.79
3	-43.89	-42.34	-45.08	-48.01
Delta	5.83	0.87	5.14	9.21
Rank	2	4	3	1
Response Table for Means				
Level	Torque	Injection Pressure	Fuel	Timing
1	111.00	142.67	144.67	103.00
2	167.33	165.33	124.00	97.00
3	174.00	144.33	183.67	252.33
Delta	63.00	22.67	59.67	155.33
Rank	2	4	3	1

Analysis of Variance (ANOVA)

ANOVA is a statistically built, objective judgement-making tool for identifying any dis similarities in the average performance of groups of items that were verified. ANOVA aids in analyzing the importance of all-required factors and their interactions by matching the average square against an Estimate of the experimental errors at specific confidence levels. This analysis was conducted for a level of significance of 5% (that is the level of confidence of 95%). Table 4 displays the ANOVA

Results

Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Torque	1	5953	5953	1.72	0.237	9.90
Timing	1	33451	33451	9.69	0.021	55.6422
Error	6	20713	3452			34.958
Total	8	60118				100

It can observed from the ANOVA analysis that the timing (55.6422%) has the more influence on NOx. The last column of table shows the percentage contribution of each parameter on the total variation representing their degree of impact on the result. The torque (9.90%) and Timing (55.6422%) has the greatest influence on the NOx and other factors have negligible influence on NOx.

2. Conclusion

The present paper experimental investigation on the performance parameters by Taguchi method:

- It is observed that the Torque influences more on the BP compared to the other parameters. The contribution of torque on the BP is 71.74% in compared with the other parameters by ANOVA.
- It is observed that the Torque influences more on the BSFC compared to the other parameters. The contribution of torque on the BSFC is 73.24% in reference with the other parameters by ANOVA.
- In CO the influence of the Injection pressure is more in compared with the other parameters. Injection pressure contributes 45% on CO compared to other parameters by ANOVA.
- The influence of torque is more on the HC compared to other parameters. The Torque influences 62% compared to other parameters by ANOVA.
- Timing influences more on the NOx compared with the other parameters. Timing has the influence of 63% on the NOx by using ANOVA.