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Comparative Experimental Analysis and Performance Optimization of Single-Cylinder DI and HCCI Engine with Series Catalytic Converters

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ABSTRACT

The stringent norms imposed by the government to reduce emissions to the environment have forced all engine manufacturers to reduce engine emissions. Carbon monoxide and NOx emissions from diesel engines are topics of significant consideration. This causes climate change and natural calamities. The current paper focuses on the comparative performance optimization of single-cylinder engines in DI and HCCI mode fitted with custom-designed catalytic converters in Series configuration using Taguchi regression Analysis based on experimental results obtained for series combination. The present work tested a diesel engine in both DI and HCCI modes with catalytic converters in series configurations with various monolith lengths and compression ratios. The test results are then analyzed using the Taguchi method and regression analysis. Overall, BTE is higher for HCCI mode than DI mode with the series arrangement of catalytic converters in the 24% to 35% range. Meanwhile, BSFC is lower for HCCI mode, in the 20% to 64% range. Hydrocarbon emission is higher, starting from 15% to 48%. The NOx emissions are lower for lower load, but on full load, they are more than those in DI Mode. CO emissions are also Higher for HCCI mode in the 12% to 30% range.

1. Introduction

Research has been done in the last few years to look into different methods for substituting diesel fuel emissions. To meet their power needs, developing nations rely heavily on DI engines. But pollution is the main issue. Numerous methods are employed to address these issues. One method for ensuring proper system function is the Taguchi method [1]. Energy used for the intended function divided by energy wasted is called the S/N ratio. The purpose of the S/N ratio is to identify controllable elements that mitigate the impacts of uncontrollable factors (noise). The most significant S/N ratio-selected factors provide the best value with the slightest variation. To determine the S/N ratio using characteristic values for BSFC, CO, HC, and CO_2, the more

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accustomed one is used to obtain the best result, and the higher, the better characteristic is employed for BTE to lower. Significant effects on BSFC and CO emission are caused by load and compression ratio, respectively [2]. When the Compression Ratio and Load rise, BTE drops. The principal component analysis based on Taguchi can be utilized to obtain the best outcomes for the experimental readings [3]. Kathirvel *et al.,* [4] assessed the performance of diesel fuel made from fossil fuels and combined with cotton seed and lin seed oils using specific blend ratio specifications. His study used fuel usage and load Response surface methodology for optimization, and the actual and theoretical findings showed a 4% error.

Rao and Reddi [5] optimized the DI diesel engine's performance using diethyl ether and mahua methyl ester as fuel. The main parameters under consideration were load, fuel input, exhaust gas temperature, BTE, and emissions characteristics. Also, the S/N Ratio and grey regression analysis are used to determine the ideal parameters. Engine performance optimization was carried out by Agrawal *et al.,* [6] utilizing Taguchi multiple regression and artificial neural networks. With input parameters of % blend, Load, RPM, Kusum oil ethyl ester, and butanol mix, Taguchi and ANN are superior optimization strategies. When diesel engine performance was assessed using Jatropha biodiesel as fuel, Patil and Arakerimath [7] discovered lower efficiency and increased fuel consumption for 40% of blends. Still, satisfactory results are observed for 20% blends with diesel.

An engine with homogeneous charge compression ignition performs well and emits less particulate matter and nitrogen oxide. Three crucial governing factors for the HCCI engine are the A/F ratio, CR, and IAT. PCCI, RCCI, and PFI are techniques used for fuel injection in HCCI mode.PCCI is one of the essential techniques for improving HCCI engine performance while reducing emissions [8-10]. When considering HCCI combustion, factors including HRR, combustion duration, and thermal efficiency must be considered [11,12]. In the current study, catalytic converter-equipped DI and HCCI engines are tested under varied engine circumstances to determine the engine's performance. The catalytic converter's design geometry for diesel engines affects performance and conversion efficiency. Lean NOx traps can be used to diagnose problems [13]. The HCCI engine with biodiesel blends shows low peak HRR. High injection pressure lowers NOx emission while HC and CO emission increases with Biodiesel Blend in HCCI engine [14]. Due to adding Naptha/n heptane lean mixture blends, HCCI combustion occurs at high speed. ITE increases by 8%, and retarded combustion is observed due to the high octane number for n-heptane. Naptha fuel blend can improve the operating range of HCCI engines, but CO and HC emissions increase due to Naptha [15]. The variation of oxygen in HCCI combustion affects the performance. The optimum value of 60% oxygen gives maximum pressure, temperature, HR, increased CO oxidation, and reduced UHC.

Further addition of oxygen up to 80% increases NO. Also, adding oxygen to HCCI combustion increases the low-load operating range. It also increases engine efficiency and reduces CO and HC emissions compared to natural gas-fueled Engines—hydrogen and oxygen addition causes advancement SOC [16]. The power density and thermal efficiency of the HCCI engine are higher and lower than those of the conventional oneHCCI, PCCI, and dual fuel PCCI techniques to help reduce NOx and PM emissions [17]. It isn't easy to control the combustion phase, and high HC and CO emissions are seen [18]. Adding acetone in N Heptane in HCCI combustion decreases cylinder pressure and HRR while BSFC and IMEP increase. Crank angle is one of the significant parameters for engine performance [19]. Maximum cylinder pressure and HRR decrease with increased ethanol blends in the HCCI engine. It is found that MPRR increases with an increase in equivalence ratio [12]. Palm oil blends in HCCI Di engine increase BSFC and reduce engine performance. It also reduces CO2 emissions but increases NOx and UHC emissions.

Recent studies highlight various optimization techniques to enhance engine performance. For instance, Pathan *et al.,* [20] investigated the impact of nozzle pressure ratios and control jet locations on base pressure in suddenly expanded flows, emphasizing the role of flow control in improving performance. Additionally, optimization of nozzle designs and area ratios has been explored to reduce drag and enhance thrust efficiency in high-speed flows [21-23].

The design of catalytic converters, particularly the impact of inlet cone angles on flow distribution, has been studied extensively. Shaikh *et al.,* [24,25] performed CFD analysis to assess the effectiveness of different cone angles on the performance of three-way catalytic converters, showing that optimized designs can lead to better flow uniformity and reduced pressure drop. These findings are crucial for integrating catalytic converters in engine systems to meet stringent emission regulations while maintaining high performance.

Computational Fluid Dynamics (CFD) has become an essential tool in engine performance optimization. Studies have used CFD to analyze various parameters affecting flow dynamics, pressure distributions, and performance in DI and HCCI engines. Pathan *et al.,* [26,27] explored the effect of area ratios and Mach numbers on velocity in suddenly expanded flows, providing insights into optimizing engine components for better performance. Furthermore, CFD analysis has been applied to investigate base pressure variations and control strategies in high-speed flows [28,29].

Experimental studies complement CFD analyses by providing empirical data to validate computational models. Khalil *et al.,* [30] investigated local Nusselt number profiles to augment heat transfer, demonstrating practical applications of CFD findings in industrial contexts. Additionally, studies on heat sink orientations and their effects on thermal performance have contributed to understanding the practical implications of engine optimization strategies [31].

There, engines need to optimize the catalytic converter performance for HCCI engines to reduce harmful emissions. The series arrangement of a catalytic converter in the HCCI engine helps to maximize the emissions and improves the backpressure, ultimately helping to improve the performance of the HCCI engine.

2. Methodology

2.1 Setup for the Experimentation

This study uses a single-cylinder, four-stroke, variable compression ratio, water-cooled diesel Research engine. It is modified to operate in DI mode and HCCI mode with external mixture formation,i.e., port fuel injection with biodiesel vaporizer, as shown in Figure 1 and Figure 2. ECU controls the timing and amount of fuel supplied. The experiments were conducted at a constant speed of 1500 rpm. The engine details are displayed in Table 1. A Design of Experiment (DOE) technique increased efficiency and streamlined the experimental process. This method's careful selection and control of particular characteristics made it possible to reduce the total number of experiments needed. The selected parameters for the trials were the engine load, the compression ratio, the temperature of the warmed air, and the monolith length in the catalytic converter. The researchers could efficiently design their tests using the DOE methodology, reducing the time and resources needed. The engine was connected to a dynamometer with a strain gauge load sensor installed—an analyzer for gases that measures NOx, CO_2, HC, CO, and O_2. The engine was equipped with a catalytic converter and operated in diesel and HCCI modes, utilizing the port fuel injection method. 25%, 50%, and 100% of the load was applied, and the compression ratio ranged from 14 to 18. HC, CO, NOx, CO_2, and O_2 emission levels were measured using an AVL4 5 gas analyzer. The smaller, better S/N ratio was the basis for adjusting the response parameters for BSFC, HC, CO, NOx, and CO2.

Fig. 1. Single cylinder dual mode Di engine test setup

Fig. 2. Series catalytic converter arrangement

Table 1
Engine details

Parameter	Specifications
Engine type	Four-stroke Single-cylinder water-cooled diesel engine
Make by	Kirloskar Oil Engines Ltd
Rated Power	3.5 Kw
Rated Speed	1500 rpm
Bore dia	87.5 mm
Stroke length	110mm
Compression ratio	12-18

$$S/N = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \tag{1}$$

where yi is the value measured by the response variable i, a negative sign signifies that the most significant value gives the response variable's optimal value. Table 2 lists the process parameters and amounts chosen for examination because they significantly impact the goal of reducing emissions and increasing fuel efficiency. The L9 Orthogonal Array for a diesel engine equipped with a catalytic converter is displayed in Table 3. Comparably, Table 4 shows the L9Orthogonal Array for the HCCI engine fitted with a catalytic converter. Nine experiments were carried out on both engines, and the results were recorded. The Taguchi Analysis Method is used to optimize the results, and respective S/N ratios are computed for various parameters. S/N ratio explanations are given in Results and Discussion.

Table 2
Parameters and Level for DI and HCCI mode with catalytic converter

Process parameters	Notation	Units	Level1	Level 2	Level3
Monolith Length	L	mm	5	10	20
Load	P	%	25	50	100
Compression ratio	CR	-	14	16	18

Table 3
L9 Orthogonal Test Array for DI mode with a series arrangement of catalytic converter

	Input Parameters			Output Parameters					
	Monolith Length (mm) L mm	Compression ratio CR	Load P %	BTE %	BSFC kg/kwWh	HC ppm	CO ppm	NOx ppm	CO2 ppm
1	5	14	25	11.61	0.74	35	0.08	87	2.2
2	5	16	50	18.21	0.47	32	0.05	179	2.8
3	5	18	100	21.58	0.4	41	0.13	210	3.5
4	10	14	50	16	0.54	33	0.07	144	2.8
5	10	16	100	22.71	0.38	39	0.16	161	3.3
6	10	18	25	11.9	0.72	16	0.05	103	2.1
7	20	14	100	21.98	0.39	31	0.13	148	3
8	20	16	25	11.32	0.76	20	0.07	76	2.2
9	20	18	50	16.19	0.53	12	0.04	156	2.5

Table 4
L9 Orthogonal Test Array for HCCImode with a series arrangement of catalytic converter

	Input Parameters			Output Parameters					
	Monolith Length (mm) L mm	Compression ratio CR	Load P %	BTE %	BSFC kg/kWh	HC ppm	CO ppm	NOx ppm	CO2 ppm
1	5	14	25	16.1	0.53	51	0.08	87	2.2
2	5	16	50	22.9	0.37	53	0.05	179	2.8
3	5	18	100	29	0.3	47	0.13	210	3.5
4	10	14	50	22.8	0.38	44	0.07	144	2.8
5	10	16	100	28.2	0.3	58	0.16	161	3.3
6	10	18	25	18.1	0.47	51	0.05	103	2.1
7	20	14	100	29.8	0.29	43	0.13	148	3
8	20	16	25	15.1	0.57	45	0.07	76	2.2
9	20	18	50	25.5	0.34	44	0.04	156	2.5

3. Results and Discussion

3.1 Performance Characteristics

3.1.1 Brake thermal efficiency

Figure 3 compares BTE fluctuation with load for the DI engine and HCCI engine mode with series catalytic converters. BTE was 34%,24%, and 35% greater for HCCI mode compared to DI mode series catalytic converter arrangement for full load with compression ratio 18, 16, and 14, respectively, and monolith length 5mm, 10mm, and 20mm, respectively. The finding has shown that for series catalytic converter arrangements in HCCI engine mode, BTE is higher in series arrangements. Compared to the DI model series catalytic converter combination. Overall, BTE is higher in HCCI Mode for both DI and HCCI mode for series catalytic converter configurations.

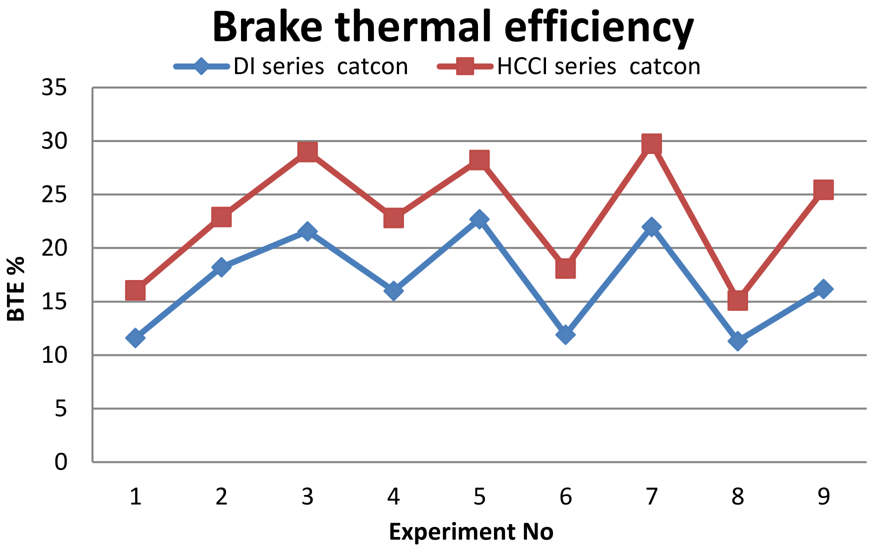

Fig. 3. Brake Thermal efficiency for Di mode and HCCI mode series arrangements

3.1.2 Brake-Specific Fuel Consumption (BSFC)

Brake-specific fuel consumption measures the fuel efficiency of an engine that burns fuel and produces rotational shaft power. Figure 4 shows that the brake-specific fuel consumption is higher for DI mode compared to HCCI mode for all conditions. Particularly for full load conditions with compression ratios 18, 16, and 14, respectively, and monolith lengths 5,10, and 20mm, the BSFC is lower in HCCI mode by 25%, 21%, and 25.64 %. So, fuel consumption is lower in HCCI mode, even for a series of catalytic converters.

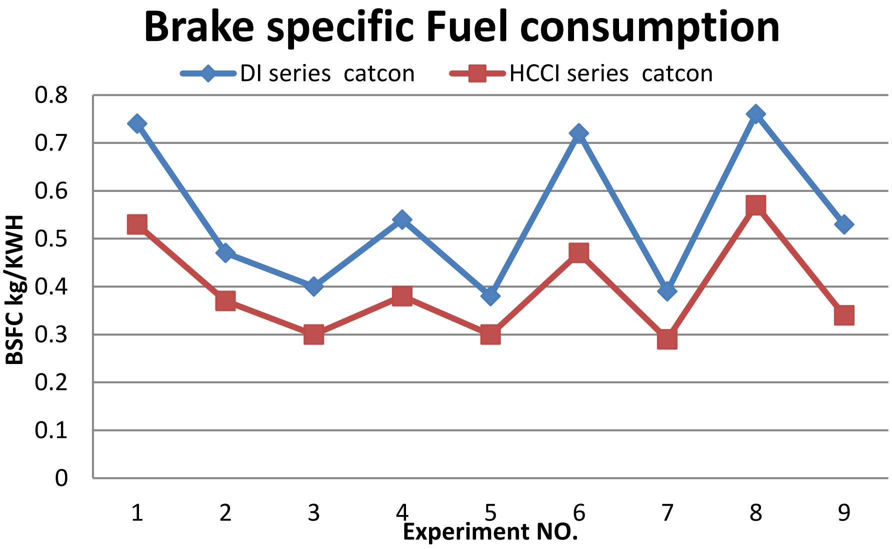

Fig. 4. Brake-specific fuel consumption for Di mode and HCCI mode series arrangements

3.2 Emission Characteristics
3.2.1 Hydrocarbon emission (HC)

Overall, from the experimental results, hydrocarbon emissions are slightly lower for the DI mode than for the HCCI mode. Particularly at full load conditions, the values are 14.63%, 48.71%, and 38.70% lower for DI Mode with compression ratios of 18, 16, 14, and monolith lengths 5, 10, and 20mm, respectively, from Figure 5.

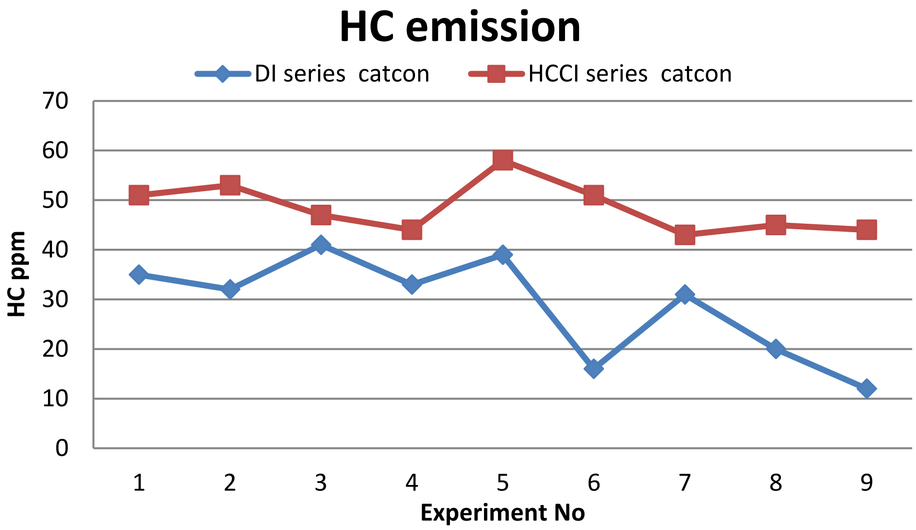

Fig. 5. Hydrocarbon Emissionfor Di mode and HCCI mode series arrangements

3.2.2 Nitrogen Oxides Emission (NOx)

Figure 6 shows the comparative effect of load on emissions of nitrogen oxides for DI mode and HCCI mode with a series arrangement of catalytic converters. From the figure and experimental results, it has been found that NOx emissions are 4.6 %, 11.17%, 28%, 15%, 9 %, and 21% lower for HCCI mode for 25% and 50% load But on the contrary, when full load is applied The NOx emission is observed to be 13%, 27% and 12% Lower for DI mode compared to HCCI mode for different monolith lengths. So overall, NOx emissions are lower for HCCI mode for lower loads, but at full load, NOx emissions are slightly higher than diesel Mode.

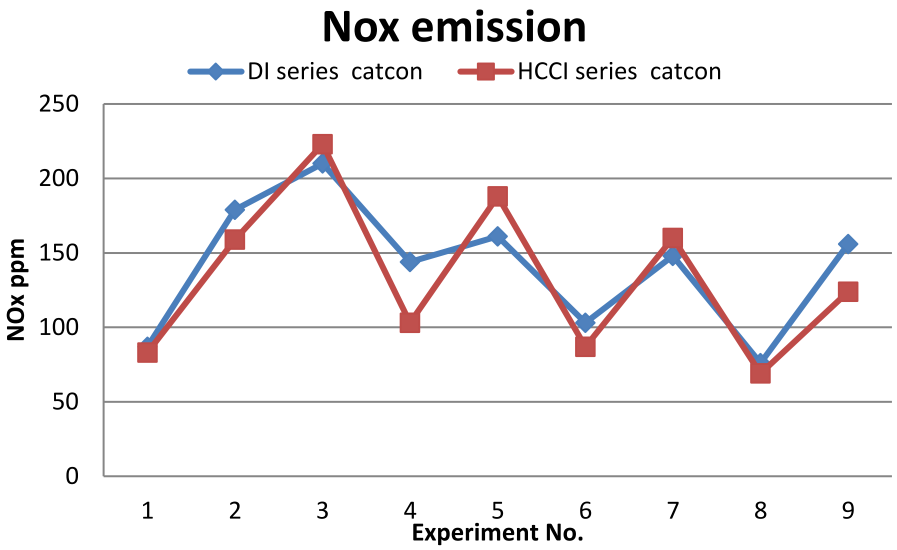

Fig. 6. Nitrogen Oxides Emission for Di mode and HCCI mode series arrangements

3.2.3 Carbon Monoxides Emission (CO)

Carbon monoxide is a flammable, poisonous gas with no color, odor, or taste but very harmful to the environment. Figure 7 shows the variation of Carbon monoxide emission against load for diesel engines with DI and HCCI mode with series catalytic converter arrangement. The carbon monoxide emission for Di mode is 30.76%,12.5%, and 30.76 % lower than HCCI mode for series catalytic converter arrangement for 18, 16, and 14 Compression ratios and 5, 10, and 20 mm monolith Length for full load conditions.

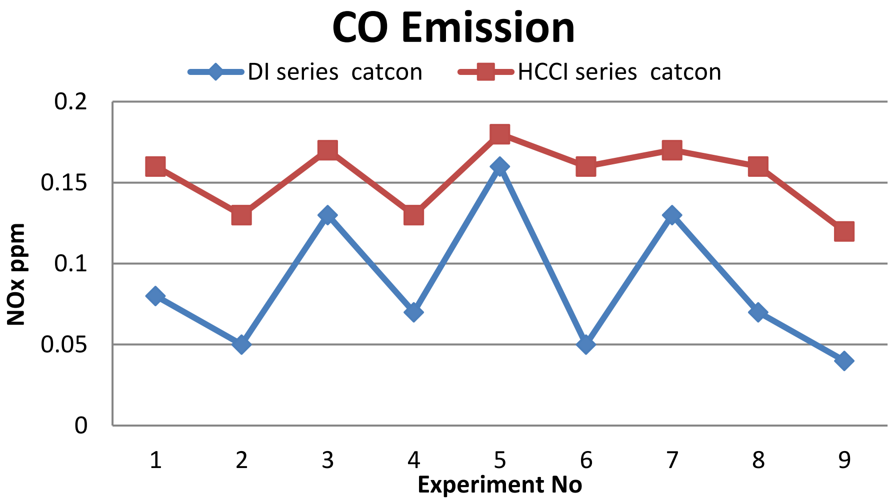

Fig. 7. Carbon Monoxides Emission for Di mode and HCCI mode series arrangements

Experimental testing is conducted on a single-cylinder diesel engine using a catalytic converter in both the HCCI and DI modes. With three-factor and three levels, the predicted efficiency is always more significant, as shown by the S/N ratio for brake thermal efficiency in Figure 8 . Brake-specific fuel consumption, HC, CO, NOx, and CO2 S/N ratios are shown in Figure 9, Figure 10, Figure 11, Figure 12, and Figure 13. The more minor, the better features, as expected values for these parameters are lower, and the better for diesel mode. Comparably, Figure 14 displays the S/N ratio for brake thermal efficiency on the more significant, the better characteristic, indicating that there are three factors, three levels, and a constant increase in expected efficiency. Brake-specific fuel consumption, HC, CO, NOx, and CO2 S/N ratios are shown in Figure 15, Figure 16, Figure 17, Figure 18, and Figure 19. The more minor, the better characteristics, as expected values for these parameters are lower, and the better for HCCI mode.

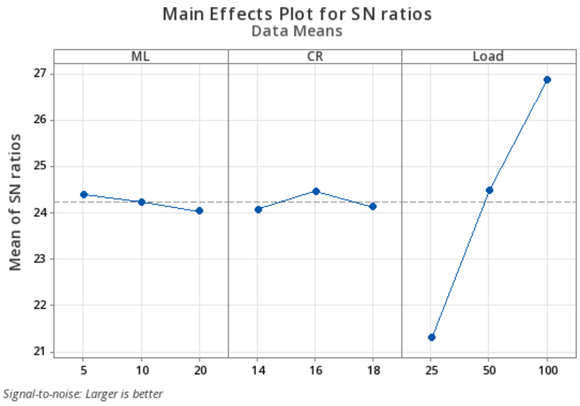

Fig. 8. BTE Verses ML, CR, Load

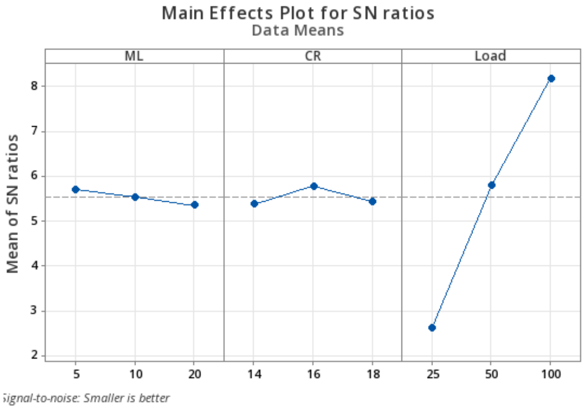

Fig. 9. BSFC Verses ML, CR, Load

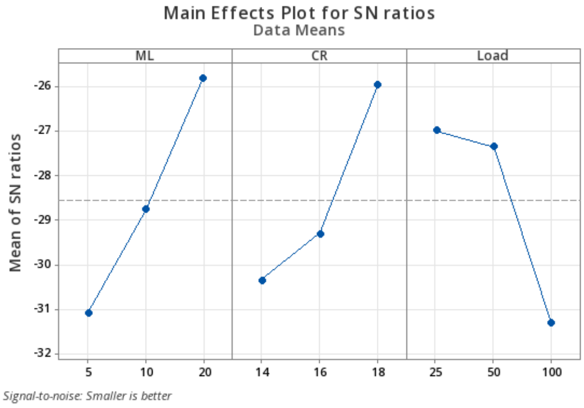

Fig. 10. HC Verses ML, CR, Load

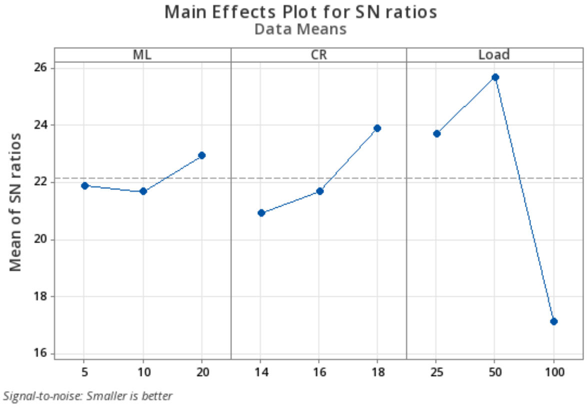

Fig. 11. CO Verses ML, CR, Load

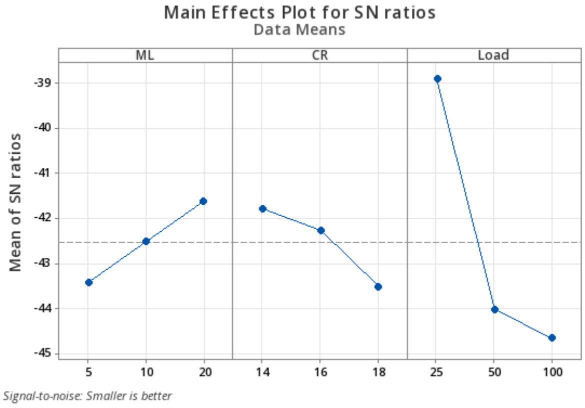

Fig. 12. NOX Verses ML, CR, Load

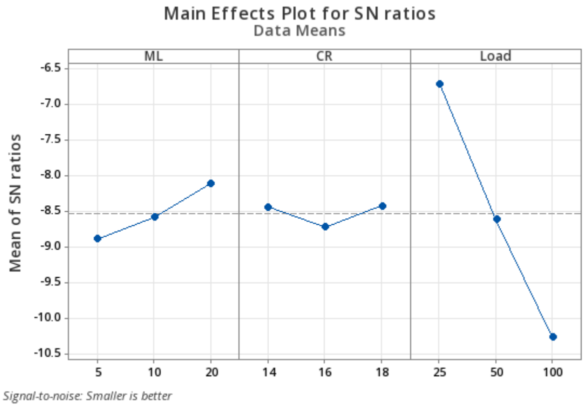

Fig. 13. CO2 Verses ML, CR, Load

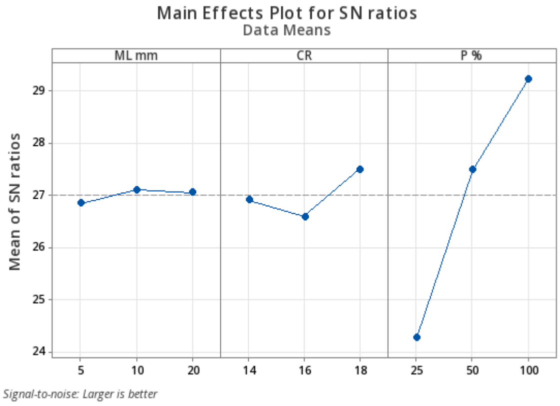

Fig. 14. BTE Verses ML, CR, Load

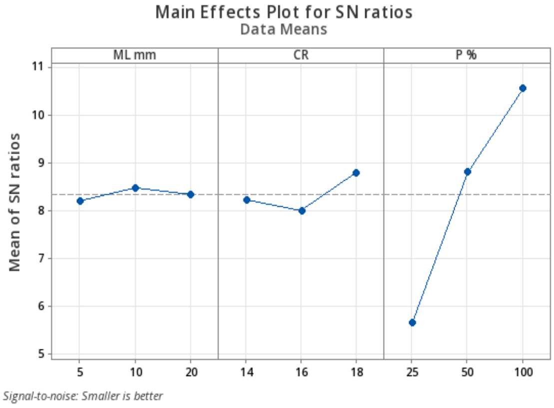

Fig. 15. BSFC Verses ML, CR, Load

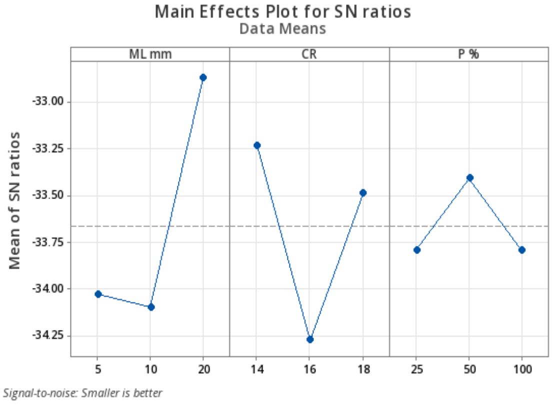

Fig. 16. HC Verses ML, CR, Load

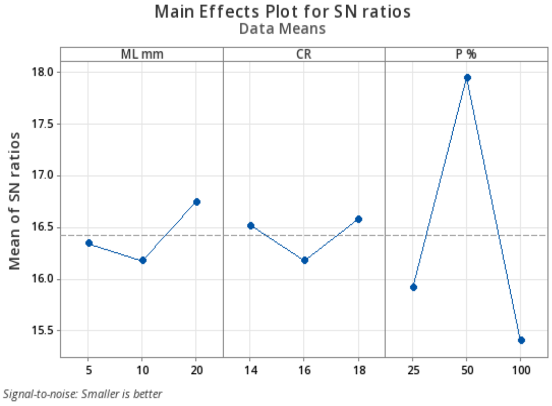

Fig. 17. CO Verses ML, CR, Load

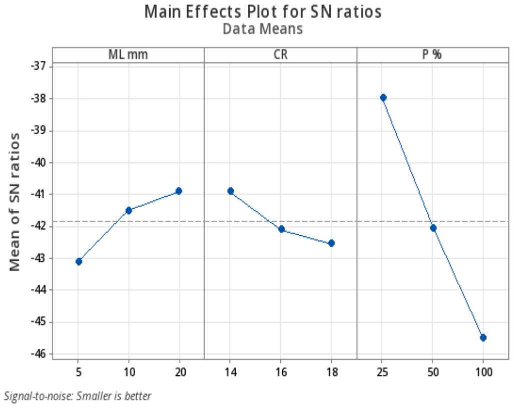

Fig. 18. NOX Verses ML, CR, Load

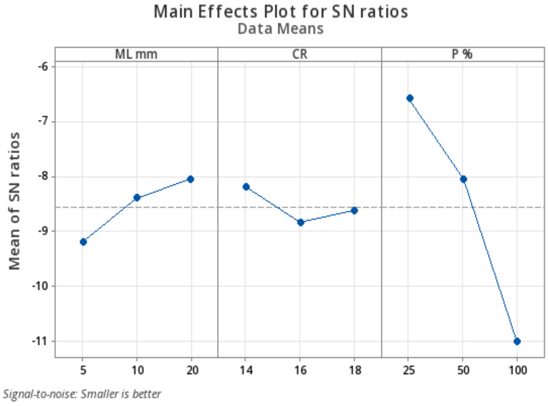

Fig. 19. CO2 Verses ML, CR, Load

3.3 Analysis of S/N Ratio

This is done to reduce noise in the response or uncontrollable elements by identifying those that can be controlled. Factors with the highest signal-to-noise ratio are chosen for the best value with the slightest fluctuation. S/N ratios in Figure 8 to Figure 13 for DI engines and Figure 14 to Figure 19 for HCCI engines indicate the relative importance of each parameter. Versus, The difference between the maximum and lowest Signal to Noise levels on a factor-level graph is called the delta. Table 5 and Table 6 show S/N ratio values for DI and HCCI engines fitted with series catalytic converters for different parameters like BTE, BSFC, HC, CO, NOx, and CO2 for three factors Monolith length ML, compression Ratio CR, and load for three levels along with delta values.

Table 5
S/N ratio values for DI Engine with series catalytic converter for different parameters at different levels

Response	Factor	Level 1	Level 2	Level 3	Delta	Rank
BTE	ML	24.39	24.24	24.03	0.36	3
	CR	24.07	24.47	24.13	0.40	2
	Load	21.29	24.49	26.88	5.59	1
BSFC	ML	5.711	5.537	5.359	0.352	3
	CR	5.382	5.782	5.442	0.400	2
	Load	2.617	5.808	8.181	5.563	1
HC	ML	-31.08	-28.76	-25.81	5.27	1
	CR	-30.36	-29.31	-25.97	4.39	2
	Load	-26.99	-27.35	-31.3	4.31	3
CO	ML	21.89	21.68	22.93	1.25	3
	CR	20.92	21.68	23.9	2.98	2
	Load	23.69	25.69	17.12	8.57	1
NOx	ML	-43.43	-42.52	-41.63	1.8	2
	CR	-41.79	-42.27	-43.52	1.73	3
	Load	-38.89	-44.03	-44.66	5.77	1
Co2	ML	-8.891	-8.586	-8.117	0.774	2
	CR	-8.445	-8.721	-8.428	0.292	3
	Load	-6.714	-8.615	-10.265	3.551	1

Table 6
S/N ratio Values for HCCI Engine with series catalytic converter for different parameters with different levels

Response	Factor	Level 1	Level 2	Level 3	Delta	Rank
BTE	ML	26.85	27.11	27.06	0.26	3
	CR	26.92	26.60	27.51	0.91	2
	Load	24.28	27.49	29.24	4.96	1
BSFC	ML	8.203	8.473	8.335	0.271	3
	CR	8.224	7.992	8.795	0.803	2
	Load	5.652	8.804	10.556	4.904	1
HC	ML	-34.03	-34.10	-32.87	1.23	1
	CR	-33.23	-34.27	-33.49	1.04	2
	Load	-33.79	-33.41	-33.79	0.39	3
CO	ML	16.34	16.18	16.75	0.57	2
	CR	16.52	16.18	16.57	0.40	3
	Load	15.92	17.95	15.40	2.55	1
NOx	ML	-43.13	-41.51	-40.91	2.22	2
	CR	-40.91	-42.10	-42.54	1.63	3
	Load	-37.98	-42.05	-45.51	7.53	1
Co2	ML	-9.204	-8.392	-8.051	1.154	2
	CR	-8.185	-8.838	-8.623	0.653	3
	Load	-6.579	-8.051	-11.017	4.438	1

3.4 Taguchi Main Effect for SN Ratio Plots for DI Engine with Series Catalytic Converter

Figure 8 illustrates the main effects plot for DI engine mode with a series configuration of catalytic converters for three factors and three levels. The control factors are Monolith Length, Compression ratio, and Load. As the BTE must be maximum, the Larger the better characteristics are implemented. The graph demonstrates that load has a Major Influence, followed by the compression ratio, and the most negligible influence is due to Monolith length.

Figure 9 shows the main effect plot for the same engine mode and configuration control factors for Brake specific fuel consumption. The smaller, the better the load has maximum effect, followed by the compression ratio and the minimum impact of monolith length.

Figure 10 to Figure 13 show the main plot of effect for HC, CO, NOx, and CO2 emission for the series catalytic converter in DI mode. As the goal is to reduce HC and CO, NOx, and CO2 emissions, the smaller the better criteria are used. The result shows that all three parameters, load compression ratio, and monolith length, significantly affect HC emission. In contrast, load contributes more in the case of CO emission, followed by compression ratio and monolith length.

3.5 Regression Analysis

This is the technique used to determine mathematical relations between independent and dependent variables. The dependent variable is a function of the independent variable.

$$Z = a_0 + a_1x_1 + a_2x2 + a_3x_3 + ... + a_nx_n$$

Z is the dependent variable, a_o to a_n equation parameters, and x_1 to x_n independent variables. The quality of linear fit depends on the coefficient of determination R2 [6].

Table 7 and Table 8 below show mathematical models for BTE, BSFC, HC CO, Nox, and CO_2 for DI and HCCI mode, respectively, by regression analysis. From Table 7, it can be seen that, for the DI engine case, the load has more influence of BTE, the compression ratio has more impact on BSFC, HC, CO, and NOx emission, and the monolith length influences the CO_2 emission. From Table 8, the HCCI engine case compression ratio has more influence on BTE, BSFC, NOx, and CO2 emission, and Monolith length influences the HC and CO emission.

Table 7
Regression Analysis DI Mode series catalytic converter BTE, BSFC, HC CO NOx CO2 versus ML mm, CR, P %

Sr NO	Regression equation	Most Influencing Parameter
1	BTE =9.35 - 0.0417 ML + 0.007 CR + 0.1349 Load	Load has better control on BTE
2	BSFC = 0.811 + 0.00152 ML - 0.0017 CR - 0.004352 Load	The compression ratio has better control on BSFC
3	HC = 69.4 - 0.976 ML - 2.500 CR + 0.1848 Load	Compression ratio has better control on HC
4	CO = 0.1100 - 0.00057 ML - 0.00500 CR + 0.001086 Load	The compression ratio has better control over CO
5	Nox = -15.1 - 1.96 ML + 7.50 CR + 1.002 Load	Compression ratio has better control on NOx
6	CO_2 = 1.956 - 0.01762 ML + 0.0083 CR + 0.01419 Load	Monolith Length has better control on CO2

Table 8
Regression Analysis HCCI Mode series catalytic converterBTE, BSFC, HC CO NOx CO2 versus ML mm, CR, P %

Sr NO	Regression equation	Most Influencing Parameter
1	BTE = 7.97 + 0.051 ML mm + 0.326 CR + 0.1587 P %	The compression ratio has better control on BTE
2	BSFC = 0.674 + 0.00024 ML mm - 0.0075 CR - 0.002781 P %	The compression ratio has better control on BSFC
3	HC = 47.9 - 0.462 ML mm + 0.33 CR + 0.0105 P %	Monolith Length has better control on HC
4	CO = 0.1444 - 0.00052 ML mm - 0.00000 CR + 0.000238 P %	Monolith Length has better control on CO
5	NOx = -42.2 - 2.252 ML mm + 7.33 CR + 1.441 P %	Compression ratio has better control on NOx
6	CO2 = 1.106 - 0.02476 ML mm + 0.0500 CR + 0.01933 P %	The compression ratio has better control on CO2

3.5.1 Optimum values of parameters

The following are the ideal settings for the parameters when comparing the Di engine and the HCCI engine.

When it comes to diesel engines in DI mode in series catalytic converter configuration, BTE is at its best at monolith length 5, compression ratio 16 loads 100%; when it comes to HCCI mode in a series catalytic converter, monolith length 10, compression ratio 18 loads 100%. Similarly, for DI Mode, BSFC is at its best at monolith length 5, compression ratio 16 loads 100%, and monolith length 10, compression ratio 18 loads 100%. Similarly, hydrocarbon emission is best for monolith lengths of 20 and 20, with a compression ratio of 18 and 14 and a load percentage of 25% and 100% for Di and HCCI modes, respectively. The ideal carbon monoxide emission values for DI and HCCI modes are monolith length 20, compression ratio 18, and load 50%. The ideal monolith length for nitrogen oxide emissions is 20, the compression ratio is 14 load of 25% for DI and HCCI modes, and finally, the perfect monolith length for carbon dioxide emissions is 20, with a compression ratio of 18 loads of 25% for DI and monolith length 20, and compression ratio 14 loads 25% for HCCI.

4. Conclusions

This study uses HCCI and conventional DI engines to test a traditional diesel engine's performance and emissions. The study looks at the effects of three distinct factors on engine performance and emissions: Load, compression ratio, and catalytic monolith length. Using Taguchi analysis, nine experimental sets of runs based on the Taguchi L9 Orthogonal Array are conducted to comprehend the effect of a series arrangement of catalytic converters on engine emissions. Minitab software uses the experimental readings to create the Signal to Noise ratio charts. The results underscore the significance of the monolith's length in regulating and lowering pollutant outputs by showing that it significantly affects engine emissions. Overall, BTE is higher for HCCI mode than DI mode with the series arrangement of catalytic converter in the range of 24% to 35%. At the same time, BSFC is lower for HCCI mode in the range 20% to 64%. Hydrocarbon emission is higher, starting from 15% to 48%. The NOx emissions are lower for lower load, but for full load, they are more than those in DI mode. CO emissions are also higher for HCI mode in the 12% to 30% range.

The regression analysis results show load has better control on BTE for DI mode. Monolith length has control over BSFC and CO2 as well, and Compression ratio has more control over HC, CO, and NOX. In contrast, for HCCI mode, the Compression ratio has better control over BTE, BSFC, NOx, and CO2, and Monolith length has control over HC and CO.

Conflict of Interest

The Authors declared no potential conflict of interest concerning this article's research, authorship, and publication.

Ethics

There are No Ethical issues with the publication of this manuscript.

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