

Research Article

Experimental Investigation on Impact of EGR Configuration on Exhaust Emissions in Optimized PCCI-DI Diesel Engine

Getachew Alemayehu,¹ Ramesh Babu Nallamotheu ,¹ Deresse Firew,¹ and Rajendiran Gopal²

¹Department of Mechanical Engineering, SoMCME, Adama Science and Technology University, Adama, Ethiopia

²Department of Motor Vehicle Engineering, Defense University, College of Engineering, Bishoftu, Ethiopia

Correspondence should be addressed to Ramesh Babu Nallamotheu; rbnallamotheu@gmail.com

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The main objective of this work is to analyse the impact of different EGR configurations (no EGR, cold EGR, and hot EGR) on exhaust emissions of PCCI-DI engine. Methanol port injection, dieseline direct injection, advanced injection timing, and different EGR rates were adapted and optimized on the baseline engine. A hybrid algorithm of grey relational analysis with the Taguchi method was implemented for optimization. Results were compared among the PCCI-DI combustion strategy with the baseline using cold EGR, hot EGR, and no EGR configurations. Both cold and hot EGR configurations resulted in lower emission of NO_x plus smoke at different loads. At low loads, hot EGR showed promising results of lower HC and CO than the cold EGR with a difference of 18.33% and 33.3%, respectively. NO_x and smoke reductions simultaneously and better trade-offs were obtained using cold EGR configuration.

1. Introduction

NO_x and soot reduction simultaneously was achieved through the advanced combustion approach, that is, PCCI. This could be achieved through advanced injection timing and a greater level of EGR resulting decrease in cylinder temperature even though HC and CO emissions have resulted. The reduction of NO_x by applying EGR in diesel engines is through the reduction in oxygen amount and combustion flame temperature. PCCI combustion techniques through advanced injections mostly 25° BTDC were found useful particularly at higher levels of EGR together with low compression ratios, and these resulted in a reduction of NO_x and improved combustion [1]. Even though there are small ranges of operation and increased emissions of HC and CO [2, 3], researchers pointed out the great potential of the PCCI combustion strategy compared with the other low-temperature combustion (LTC) strategies. PCCI strategy resulted in up to 97% NO_x reductions compared with conventional diesel combustion [4]. From

other research on PCCI operation, 25° BTDC of injection timing and IMEP of 287 kPa was found best due to the reasons: lower NO_x production of 3.1 g/kWh and lower CO and HC including lower smoke emissions [5]. Studies revealed that HC and CO emissions were found out 30 times greater in the PCCI type of combustion compared with the conventional CI mode of combustion [6, 7].

Application of EGR levels to 30–40% at medium and high loads resulted in a positive impact on HC emissions and a trade-off between soot and NO_x [8]. EGR technique works by lowering the percentage of oxygen and reducing the combustion flame temperature since NO_x formation takes place at higher temperatures of 2000k [9]. The decreasing temperature of the exhaust gas recirculating by the EGR cooler helps the gas mixture not to reach too high temperature and mixes well with the intake air. The tube and shell type of EGR cooler are mostly used in automotive applications for their robustness, easy maintenance, and possible improvement [10]. Cooled water flowing from the radiator is mostly applied in heat exchangers for automotive

applications, but in this experimental setup, a separate water reservoir is designed for the cooling water supply. The recirculated exhaust gas is cooled above its condensation temperature before mixing into the incoming air which prohibits condensed water in the combustion chamber. Applying EGR became an important governing mechanism for engines working with alternative fuels and also engines working in advanced combustion modes [11] including improving engine performance [12]. Also, the modification of engines together with the application of high quality and modified fuels is very crucial in meeting the strict emission standards. In a study, the biomass-derived 1-hexanol having high cetane number and high energy density was found a hopeful and feasible biofuel for the current DI diesel engines after doing minor modifications. Blending this biofuel with the conventional fuel resulted in elongation of the ignition delay together with improved premixed combustion. Appropriate injection timing and exhaust gas recirculation rates for better combustion and emission characteristics for this fuel blend were found [13]. Influence of higher alcohols such as 5-carbon pentanol and 6-carbon hexanol blending with 30% diesel with operational setup of up to 30% EGR rate and injection timing up to 2°CA early/late were carried on a light duty direct injection diesel engine. From the study, both alcohols were found excellent alternative substitutes in place of diesel with slight DI engine modifications [14]. 30% by vol. of n-octanol in diesel was tested in this similar operational setup. From the investigation, this biofuel improved premixed combustion phasing with greater peaks of in-cylinder pressure and heat release rate than diesel. Results also indicated lower NO_x and smoke emissions with better trade-offs [15]. Performance and emission results of waste plastic oil (WPO) with blends of diesel in a DI diesel engine were studied. From the study, n-butanol addition improved consumption of fuel, better performance, and reduction of HC with increments of HC and with no effect on CO [16]. Adapting injection timing and EGR rate was done on a waste plastic oil (WPO) fueled diesel engine. The study confirmed low EGR rates together with advanced injection timing help for simultaneous reduction of smoke and NO_x [17].

Similar to most experiments implementing PCCI combustion by using a high level of EGR [18], this experiment also adapted the conventional short-route cooled EGR arrangement having a greater EGR level. The system also employs the shell and tube type heat exchanger so that coolant will circulate inside the shell, and exhaust gas circulates inside the tube. The strategy of using the maximum EGR rate for parallel reduction of PM and NO_x was investigated, and positive results were obtained [19]. EGR level up to 54% was tested which resulted in a retardation of ignition timing; also, cooled EGR with a level of 50% was investigated which helped in lowering the temperature in the compressed gasses. But, in making the EGR level high, there will be a formation of incomplete combustion that results in greater CO production [20]. An experimental study conducted uses 0 to 30% of premix ratio and from 0 to 27% of EGR variation. From the study, it was found that by increasing the level of EGR, there was a decrease in NO_x amount, but CO and HC were increased. However, for a

higher amount of premix and EGR levels, both emissions were decreased [11]. Combustion under PCCI mainly with beyond injection of 30° before TDC together with possessing 40% of EGR shows very low production of NO_x at the cost of an increase in HC and CO. This was resulted from the local flame temperature reduction and lower oxygen concentration [21].

Injection timings and EGR rates in diesel engine were optimized in a study by applying recycling waste cooking oil (WCO) which is considered to have both bio-component and recycled component features and advantages. In this finding, the response surface methodology (RSM)-based optimization having a 3-factor by 3-level full factorial DOE was implemented. Optimized results were obtained from the ternary blend D50-WCO30-Pe20, injection timing of 23°CA BTDC, and 15% EGR [22]. In another investigation, this recycled WCO is blended with diesel and n-pentanol to enhance fuel spray and other fuel features and also tested in the absence and presence of EGR. The study confirmed WCO can be efficiently reused as a source of clean energy [23]. An experimental investigation on n-octanol/diesel blend aiming for simultaneous reduction of BSFC, NO_x, and smoke was conducted using injection timing, blend composition, and EGR as control factors through the RSM technique [24]. RSM was also used in an investigation done to utilize waste plastic oil (WPO) by applying high-carbon alcohol additives to alleviate carcinogenic smoke emissions. In the finding, proper fuel blend, injection timing, and EGR rate for optimal performance and emission were obtained [25]. A 3 by 3 full factorial experimental design matrix was also carried out to optimize a blend of cyclohexanol in diesel (10%, 20%, and 30% by vol.), EGR (10%, 15%, and 20%), and time of injection (19°, 21°, and 23°CA BTDC) taken as control factors and levels. From the study, 10% by vol. of cyclohexanol/diesel blend having injection timing of 21°CA BTDC with 10% EGR rate is found optimal conditions for the chosen engine setup which resulted in the reduction of 43.1% and 32.4% of NO_x and smoke opacity, respectively, with an increase in 4% of BSFC [26].

In this study, the port fuel injection (PFI) method was used in the experimental setup in addition to the diesel direct injection since, considering its simplicity, better fuel delivery, and volumetric efficiency by using the high volatile methanol alcohol [27, 28]. A study was conducted using n-butanol port injection together with an EGR system on diesel engines. From the study, increasing the EGR level to 45% resulted in a reduction of NO_x by 97% even though a considerable soot increment was observed. By combining 47% of butanol PFI and 45% of EGR rate, there was a decrease in NO_x and soot amounts.

In this study, for the multiresponse optimization procedure, DOE and a hybrid of grey relational analysis with the Taguchi method were used. This method helped in solving complex interrelationships having multiobjective optimization problems. Taguchi including grey relational-based optimization was applied for several studies to obtain optimum emissions, performances, fuel consumptions, and fuel types [29, 30].

Engine-manufacturing companies are working for the betterment of emission restrictions. These attempts are currently become effective through applying cold EGR that lowers the peak temperature inside the combustion chamber. This will decrease the volume of intake air which could enhance the volumetric efficiency that improves the combustion efficiency. A considerable reduction of NO_x by applying a cooled EGR system has been studied, and the study demonstrated the increase in PM production due to NO_x and PM trade-off relations [31, 32]. Applying the hot EGR configuration in PCCI combustion mode resulted in better in-cylinder temperature for CO minimization and also decreased NO_x reaction rates. Hot EGR configuration is found 12.8% reduction of the total emissions of hydrocarbon in comparison with the dual-fuel PCCI baseline conditions [2].

2. Experimental Scheme and Methodology

Tests were conducted with an engine in the speed ranges of 1500 to 2500 rpm and connected to an eddy current type dynamometer for loading and timing measurements. An exhaust emission analyser for direct reading of NO_x, HC, CO, and smoke was used for the study. The engine is one cylinder, four strokes, used air as a coolant, and also comprises a computerized direct injection light-duty compression ignition engine with some modifications to form PCCI-DI combustion. Modifications performed on the selected engine including modification of fuels (port injection of methanol and direct diesel injection with different ratios), adaptation of EGR rates (25, 35, and 45%), and injection timings (230, 250, 300; advanced) were used during PCCI-DI mode of combustion. In addition, this setting was optimized for lower emission results by applying the multiresponse optimization technique of Grey-Taguchi. Table 1 shows the basic specifications of the engine and experimental settings. Fuels of gasoline, diesel, and methanol having quality standards were procured from local suppliers (their property is shown in Table 2).

The EGR cooler used for this experiment has entrances for cooling water and exhaust gas. Likewise, there are exit passages for the two fluids. The attachment of the EGR cooler with the PCCI-DI diesel engine is almost similar to most diesel engines having EGR. But, instead of using water coming from the radiator, this setup uses water coming from a separate reservoir as indicated in Figure 1. In controlling the flow level or percentage of the recirculating exhaust gas, a manually controlled gate valve is installed in the experimental setup. Temperatures of the coolant water flowing to the EGR cooler including the exhaust gas were measured using a thermometer arranged in the setup. In this experimental investigation, three scenarios of EGR configurations were considered as follows: cold EGR, hot EGR, and no EGR configurations. Cooling water is shut and drained, and the EGR flow is blocked.

The EGR cooler is designed with multiple tubes of 12 in number and uses water as a coolant. It has dimensions, an internal diameter of 12 mm, a length of tubes 40 mm, and a

TABLE 1: Engine specifications with experiment conditions.

TM3-02. Air-cooled	Diesel, one cylinder, four strokes
Stroke × bore (mm)	60 × 69
Speed (RPM)	3600
Power KW (HP)	3.5(4.8); N 80/1269/EEC-ISO 1585
Maximum torque	10.4 Nm at 2400 rpm
Port injection system	Port air-blast injection of methanol (3 bar)

tube thickness of 1 mm. The dimensions of the EGR cooler dimensions for manufacturing and assembling for this experiment were collected from published papers under optimized EGR coolers for single-cylinder diesel engines [33]. Water flowing from the radiator is mostly applied for cooling purposes in the tube and shell type of heat exchangers, but for this experimental setup, a separate water reservoir is designed for the cooling water supply having a heating mechanism to have comparable cooling water temperature with the radiator. The effects of these EGR configurations on emissions were tested at 25% of the EGR rate. Figure 2 shows a schematic diagram for the EGR cooling system. To attain steady-state conditions, the experimental engine was allowed to operate for 6 minutes, and then, the required data were collected. The average value from 3 repeated experimental tests was taken for each required test investigation.

3. Optimization Used Using Grey Relational Analysis

For the optimization process, the Grey-based Taguchi method was applied. Computing the S/N ratio was done using the following formulas [29]:

(i) Lower the better

$$\frac{S}{N} \text{ ratio}(\eta) = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^n y_{ij}^2 \right) \quad (1)$$

(ii) Higher the better

$$\frac{S}{N} \text{ ratio}(\eta) = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_{ij}^2} \right) \quad (2)$$

where n is the total number of attempts, y_{ij} is the i^{th} result of the j^{th} experiment, and $i=1, 2, \dots, n; j=1, 2, \dots, k$.

(iv) Nominal the better

$$\frac{S}{N} \text{ ratio}(\eta) = 10 \log_{10} \left(\frac{\mu^2}{\sigma^2} \right) \quad (3)$$

where $\mu = (y_1 + y_2 + y_3 + \dots + y_n/n)$

$$\sigma^2 = \frac{\sum (y_i - \bar{y})^2}{n - 1} \quad (4)$$

Selecting factors and levels (shown in Table 3) for the investigation were done by considering their effects on emissions.

TABLE 2: Chemical and physical properties of the test fuels.

Property	Test fuels and compositions					
	Diesel	Gasoline	Methanol	60% D and 40% G	80% D and 20% G	90% D and 10% G
Cetane number	52	13	5	37.48	44.13	49.62
Octane number	—	94	91	—	—	—
Density (g/ml)	0.89	0.73	0.79	0.78	0.81	0.83
Viscosity (mm ² /s)	2.501	0.64	2.49	1.803	2.06	2.1

*D-diesel, G-gasoline



FIGURE 1: Experimental setup of the PCCI-DI single-cylinder diesel engine. (1) One cylinder engine; (2) motor; (3) EGR cooler; (4) EGR valve; (5) water reservoir; (6) intake port; (7) diesel reservoir; (8) methanol reservoir; (9) air compressor; (10) smoke meter; (11) control system with a computer.

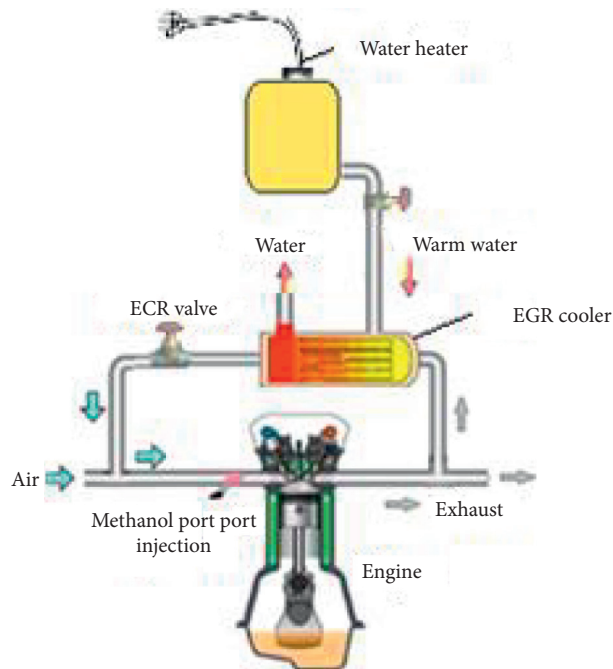


FIGURE 2: Layout of EGR system applied for the experiment.

TABLE 3: Control factors and their levels.

Parameters Code	Parameters	Unit	3 Levels		
			1	2	3
A	Injection timing (advanced)	CA BTDC	23	25	30
B	EGR rate	%	25	35	45
C	Dieseline ratio for DI (D : G)	% By Vol	60	80	90
D	Load	%	25	50	75

Normalization:

y_{ij} is normalized as z_{ij} ($0 \leq z_{ij} \leq 1$). The normalized value z_{ij} in the i^{th} emission result for the j^{th} experiment could be computed.

$$Z_{ij} = \frac{\max(y_{ij}, i = 1, 2, \dots, n) - y_{ij}}{\max(y_{ij}, i = 1, 2, \dots, n) - \min(y_{ij}, i = 1, 2, \dots, n)}, \quad (5)$$

applied in S/N ratios having lower the better (4).

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2, \dots, n)}{\max(y_{ij}, i = 1, 2, \dots, n) - \min(y_{ij}, i = 1, 2, \dots, n)}, \quad (6)$$

applied in $\frac{S}{N}$ ratio's having higher the better.

$$Z_{ij} = \frac{(y_{ij} - \text{Target}) - \min(|y_{ij} - \text{Target}|, i = 1, 2, \dots, n)}{\max(|y_{ij} - \text{Target}|, i = 1, 2, \dots, n) - \min(|y_{ij} - \text{Target}|, i = 1, 2, \dots, n)}, \quad (7)$$

applied in $\frac{S}{N}$ ratio's having nominal the best.

Grey relational coefficient (indicated in Table 4) for the normalized S/N ratio is computed by applying

$$\gamma(y_o(k), y_i(k)) = \frac{\Delta \min + \xi \Delta \max}{\Delta_o j(k) + \xi \Delta \max}, \quad (8)$$

where $j = 1, 2, \dots, n, k = 1, 2, \dots, m, n$ represents the number of experimental data items and m is the number of results.

$y_o(k)$ denotes reference sequence ($y_o(k) = 1, k = 1, 2, \dots, m$); $y_j(k)$ indicates specific comparison sequence. $\Delta_{oj} = y_o(k) - y_j(k)$ = deviation sequence, which denotes the difference of $y_o(k)$ and $y_j(k)$ in the absolute value.

$\Delta \min = \min_{j \in i} \min_{k} y_o(k) - y_j(k)$ designates the least result of $y_j(k)$.

$\Delta \max = \max_{j \in i} \max_{k} y_o(k) - y_j(k)$ designates the largest result of $y_j(k)$.

ξ is in the range ($0 \leq \xi \leq 1$). In this study, $\xi = 0.5$ [34].

During the optimization process to generate the grey relational grade as Table 4 indicates, the following formula is used:

$$\bar{\gamma}_j = \frac{1}{k} \sum_{i=1}^m \gamma_{ij}, \quad (9)$$

where $\bar{\gamma}_j$ implies grey relational grade representing the j^{th} experiment, and k denotes the number of emission features.

4. Results and Discussions

Results were analyzed and argued individually as shown in Figures 3–6, and from the results, conclusions were made. Experimental studies were followed to know and analyse the impact of EGR configurations; hot EGR, cold EGR, and no EGR configurations on emission results of the optimized PCCI-DI operation following minor and suitable modifications to lower the production of NOx, HC, and CO. The L_9 (3^4) orthogonal array matrix in Table 5 shows the nine experimental tests conducted with their results or responses obtained during the optimization process.

4.1. Emissions of NOx. From the study as shown in Figure 3, the highest value of NOx reduction (optimum), with 68.02% from the baseline diesel, was obtained from the cold EGR configuration. The least value of NOx reduction with 33.42% is found from no EGR configuration. The hot EGR configuration resulted in 63.87% NOx reductions for the load

TABLE 4: Data preprocessing for response variables.

Run No.	Taguchi design				Normalized values of S/N ratios Z_{ij}				Comparability sequence				Grey relational coefficient				Grey relational grade	Rank
	A	B	C	D	NOx	HC	CO	Smoke	NOx	HC	CO	Smoke	NOx	HC	CO	Smoke		
1	1	1	1	1	0.602	0.500	0.631	0.301	0.398	0.500	0.369	0.699	0.557	0.500	0.575	0.417	0.512	5
2	1	2	2	2	0.313	0.592	0.465	0.133	0.687	0.408	0.535	0.867	0.421	0.551	0.483	0.366	0.455	7
3	1	3	3	3	0.000	1.000	0.893	0.228	1.000	0.000	0.107	0.772	0.333	1.000	0.823	0.393	0.637	3
4	2	1	2	3	1.000	0.523	0.771	1.000	0.000	0.477	0.229	0.000	1.000	0.512	0.686	1.000	0.800	1
5	2	2	3	1	0.759	0.939	0.631	0.589	0.241	0.061	0.369	0.411	0.675	0.891	0.575	0.549	0.672	2
6	2	3	1	2	0.276	0.615	1.000	0.361	0.724	0.385	0.000	0.639	0.408	0.565	1.000	0.439	0.603	4
7	3	1	3	2	0.586	0.569	0.000	0.133	0.414	0.431	1.000	0.867	0.547	0.537	0.333	0.366	0.446	8
8	3	2	1	3	0.930	0.000	0.262	0.228	0.070	1.000	0.738	0.772	0.878	0.333	0.404	0.393	0.502	6
9	3	3	2	1	0.518	0.158	0.465	0.000	0.482	0.842	0.535	1.000	0.509	0.372	0.483	0.333	0.425	9

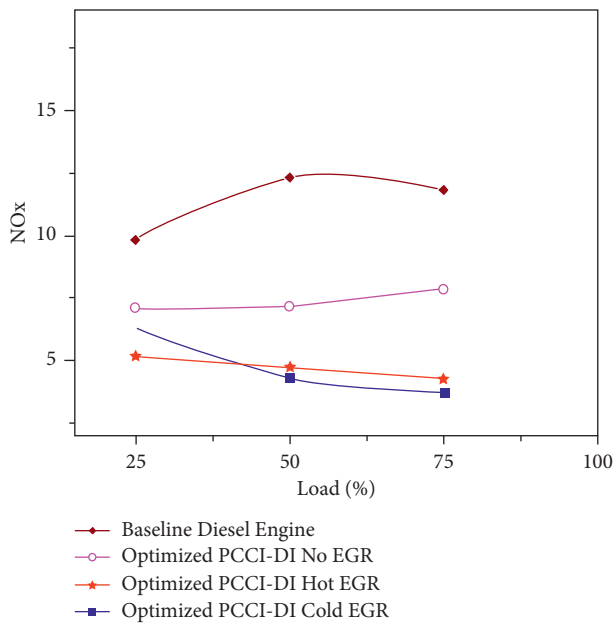


FIGURE 3: Effect of EGR configurations on NOx versus load.

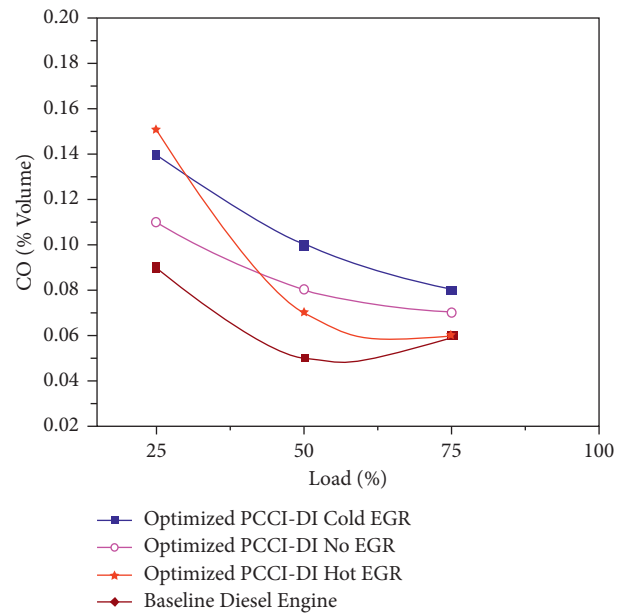


FIGURE 5: Effects of EGR configurations on CO versus load.

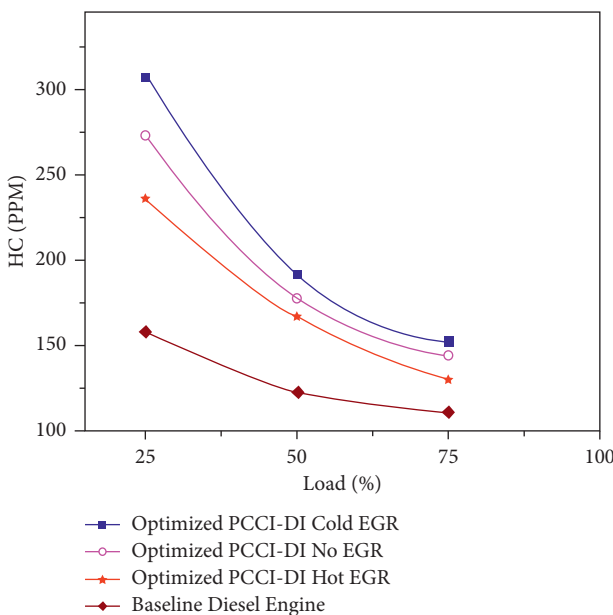


FIGURE 4: Effects of EGR configurations on HC versus load.

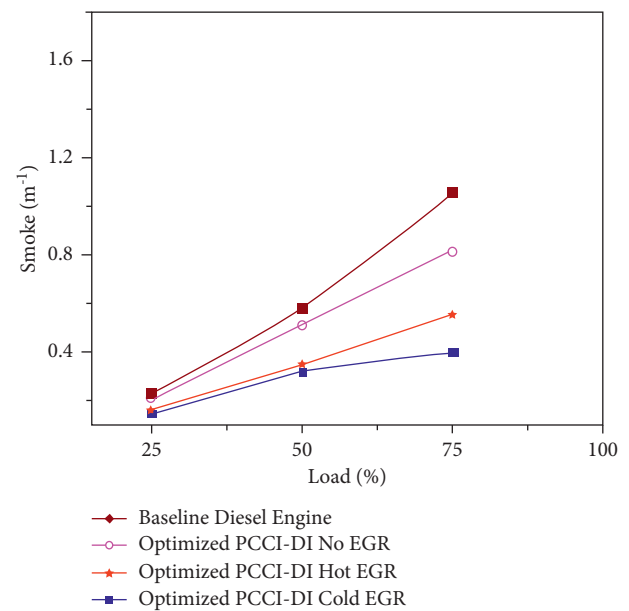


FIGURE 6: Effects of EGR configurations on smoke versus load.

TABLE 5: L_9 (3^4) Factors and responses in the orthogonal array test matrix.

Run no.	Coded Input Parameters								Responses				
	A		B		C		D						
	Injection timing (CA BTDC)	Code	Actual	EGR rate (%)	Code	Actual	Dieseline ratio (D:G) (% by vol.)	Code	Actual	Load (%)	NOx in g/kWh	HC in g/kWh	CO in g/kWh
1	-1	23	-1	25	-1	60	-1	25	2.73	153	0.06	0.05	
2	-1	23	0	35	0	80	0	50	2.10	157	0.05	0.03	
3	-1	23	1	45	1	90	1	75	1.58	176	0.08	0.04	
4	0	25	-1	25	0	80	1	75	3.92	154	0.07	0.42	
5	0	25	0	35	1	90	-1	25	3.15	173	0.06	0.12	
6	0	25	1	45	-1	60	0	50	2.03	158	0.09	0.06	
7	1	30	-1	25	1	90	0	50	2.69	156	0.03	0.03	
8	1	30	0	35	-1	60	1	75	3.68	133	0.04	0.04	
9	1	30	1	45	0	80	-1	25	2.53	139	0.05	0.02	

indicated. The reduction in NOx is mainly linked to the lowering of the oxygen amount.

Parallel reduction in NOx and smoke results having better trade-offs were obtained using cold EGR configuration.

4.2. Emissions of HC. HC is also affected by EGR configurations being cold, hot, and no EGR. As indicated in Figure 4, results showed that lower HC was found in hot EGR configuration due to improved combustion which validates the previous study by the author of [3]. In this experiment, for the optimized PCCI-DI hot EGR setting with EGR level of 25%; HC emission results from the optimized PCCI-DI hot EGR is lower by 18.3% from the Optimized PCCI-DI cold EGR configurations and increased by 9.2% from the Baseline diesel engine.

4.3. Emissions of CO. Similar to NOx and HC emissions, there is a difference in the results of CO for the different EGR configurations. As indicated in Figure 5, decreased CO was found in the cold EGR configuration of a relatively better oxygen amount than in the hot EGR scenario. At low loads, optimized PCCI-DI cold EGR indicated lower CO emissions than the hot EGR. From medium to higher loads, hot EGR indicates lower CO with a difference of 33.3% than the cold, which could be due to the better efficiency of the hot EGR at higher loads in line with the better intake air temperature for better combustion. Higher emissions of both CO and HC have resulted in low loads.

4.4. Emissions of Smoke. The positive effects of applying EGR with different configurations to lower smoke emission at all load ranges are shown in Figure 6 compared with the baseline. Both cold and hot EGR configurations indicate almost similar effects at lower loads. In the range's medium to higher loads, both hot and cold EGR show a higher percentage reduction in smoke which could be due to the better thermal efficiency and soot oxidation from the enhanced combustion temperature.

In general, in this investigation, applying different EGR configurations of cold, hot, and no EGR resulted in the reduction of NOx by 68.02%, 63.87%, and 33.42%, respectively, for the optimized operations of the PCCI-DI single-cylinder diesel engine. Similarly, lower smoke emission by 63.2%, 47.16%, and 22.64%, respectively, was registered compared with the baseline diesel engine. Percentage increments of HC and CO were minimized compared with the previous studies on PCCI combustion. 27.5%, 9.2%, and 20% increase in HC and also 33.33%, 1.7%, and 16.67% increase in CO were obtained in the cold, hot, and no EGR configurations, respectively. The study shows the possibilities of emission reductions by applying different EGR configurations on the PCCI-DI diesel engine of the types of methanol port injection and dieseline direct injection.

5. Conclusions

Considering its achievements of low emissions, the PCCI mode of combustion becomes a promising technique, especially at particular load ranges. This mode of combustion is found to be applied on diesel engines with minor and suitable modifications which lower the production of NOx, HC, and CO. In this study, the effect of EGR configurations (hot, cold, and no EGR) on emissions in this mode of combustion was investigated. Using both EGR configurations (cold and hot) helps in reducing exhaust emissions in PCCI-DI diesel engines. The impacts of using different EGR configurations on emissions on this optimized PCCI-DI diesel engine are summarized as follows.

- (i) Applying hot EGR helped to minimize the incomplete combustion in the PCCI-DI setup which has a positive effect on emissions of HC, CO, and smoke. Lower HC and CO results were obtained for low loads by using hot EGR than cold EGR configuration with a difference of 18.33% and 33.3%, respectively.
- (ii) HC and CO emissions are relatively lowered in hot EGR configuration than the others due to the increase in inlet air temperature resulting in better thermal efficiency in PCCI-DI combustion.

- (iii) Lower specific fuel consumption was also registered in hot EGR configuration than the others compared with the baseline diesel PCCI-DI operation.
- (iv) This study explored the potential of hot EGR configuration in lowering emissions of HC and CO under PCCI-DI combustion modes, particularly for methanol port injected and diesel direct-injected compression ignition engines.
- (v) The cooled EGR indicated better NO_x reductions than hot and no EGR configurations. This could be due to the effects on the amount of air mass and oxygen flow in the intake.
- (vi) Both cold and hot EGR configurations were found to affect the intake air temperature which automatically affects the combustion phenomena inside the cylinder that influences emission results.
- (vii) The no EGR configuration also showed lower HC and CO results than the cold EGR configuration in PCCI-DI combustion modes.

From the investigation, results indicated the possibility of reducing both NO_x as well as smoke together. The option of minimizing increments in HC and CO emissions by applying different EGR configurations on this PCCI-DI setup which comprises port and direct injection of methanol and diesel, respectively, was found.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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