International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Heat and Technology
Vol. 40, No. 6, December, 2023, pp. 1621-1626
Journal homepage: http://iieta.org/journals/ijht

Emission and Combustion Characteristics of Different Diesel Fuels Produced in Kurdistan-Region - Iraq

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https://doi.org/10.18280/ijht.410625

Received: 28 September 2023
Revised: 22 November 2023
Accepted: 5 December 2023
Available online: 31 December 2023

Keywords:
diesel engine, combustion, emissions

ABSTRACT

This investigation evaluates the impact of four distinct diesel fuel types, produced in Kurdistan, on a single-cylinder, direct-injection diesel engine's performance and emission characteristics at a compression ratio of 17. An experimental approach was adopted to examine the influence of fuel type on brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), and emissions including carbon monoxide (CO), unburned hydrocarbons (UHC), nitrogen oxides (NO_x), and smoke opacity. Additionally, the study scrutinized the effects of a constant cetane number (CN) across different fuel types in relation to engine output and pollutant generation. It was found that, in comparison to diesel type 1, type 3 fuel reduced smoke opacity by up to 35% while increasing BSFC by 18.18%. CO emissions associated with types 3 and 4 were 53.84% and 34.6% lower, respectively, than those measured for type 1. Except for type 1, all tested diesel variants emitted significantly lower UHC concentrations across the full load range. Conversely, diesel type 1 was linked to higher NOx emissions. The findings suggest that types 4 and 3 diesel fuels enhance combustion and emission profiles in diesel engines, presenting a potential avenue for optimization in engine performance and environmental compliance.

1. INTRODUCTION

The advent of the internal combustion engine has profoundly transformed societal engagement in routine activities. Applications of these engines are diverse, extending from the operation of compact, portable power tools to larger, static systems utilized in power generation and maritime propulsion. In the past decade, these technologies have undergone considerable advancements, spurred by escalating market demand and increased investment [1].

In the realm of automotive engineering, diesel-powered vehicles have gained a competitive edge. A broader range of models, enhanced fuel efficiency, and superior power output have collectively fostered their growing market penetration. Recent innovations in diesel engine technology have been pivotal in this expansion. Developments such as high-pressure common rail direct injection systems, refined split injection strategies, exhaust gas recirculation, and advanced turbocharging have enabled the production of more compact, lightweight diesel engines. These engines deliver augmented power and reduced emissions, marking significant progress in automotive design and environmental stewardship [2].

The exhaust stream from combustion engines is the primary conduit for the emission of pollutants. Diesel engines, in particular, are known to emit an array of contaminants, including nitrogen oxides (NO_x), total organic compounds (TOC), carbon dioxide (CO_2), carbon monoxide (CO), and particulate matter (PM). It has been established that the formation of nitrogen oxides is facilitated by the high-pressure, high-temperature conditions prevalent during combustion, coupled with the presence of nitrogen in the fuel. The generation of other pollutants such as hydrocarbons (HC), carbon monoxide (CO), and smoke is largely attributed to incomplete combustion processes. It is recognized that the flame temperature plays a crucial role in the synthesis of nitrogen oxides, with NO_x being produced predominantly in the high-temperature regions of the flame due to the dissociation of molecular nitrogen within the combustion chamber. In instances where the conversion of carbon monoxide to carbon dioxide is incomplete, CO is consequently vented into the exhaust. This typically occurs when the gas temperature during combustion is insufficiently low, resulting in a dearth of available oxygen in proximity to the hydrocarbon molecules [3].

In relation to nitrogen oxide emissions, variations have been correlated with the cetane number of the fuel, as evidenced by recent studies [4].

Incomplete combustion, which leads to the release of unburned hydrocarbons, has been frequently implicated in respiratory ailments. Particulate matter, or soot, is also associated with respiratory issues and has been linked to various malignancies through extensive studies. The high flame temperatures during combustion are responsible for the formation of nitrogen oxides (NO_x), which not only contribute to acid rain and global warming but also pose a multitude of health risks [5].

The ubiquity of internal combustion engines in applications such as transportation, electricity generation, and agricultural machinery has led to their significant role in environmental pollution. Notably, diesel engines are substantial contributors, emitting carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC) during the combustion process. The urgency to identify alternative fuels has been heightened by concerns over the depletion of conventional resources and the pressing environmental challenges faced globally [6].

Research has revealed that an increase in water content within a fuel blend corresponds to a decrease in exhaust gas temperature (EGT), nitrogen oxides (NO_x), and smoke emissions, while simultaneously enhancing brake thermal efficiency (BTE) [7].

In this context, the present study focuses on assessing the impact of high-quality diesel fuel produced in the Kurdistan region of Iraq, with the objective of improving the performance and reducing exhaust gas emissions of a diesel engine.

2. TEST ENGINE And EXPERIMENTAL PROCEDURE

The test engine specifications are displayed in Table 1. The test engine has a control panel attached to it so that it may be used for monitoring engine performance. Therefore, view the performance and combustion characteristics on the computer by this control panel. The test rig has ICE software installed to allow for the collection of different curves and operational outcomes. A calorimeter is available to measure the heat that exhaust gas dissipates. As seen in Figure 1, the test engine is fitted with an eddy current dynamometer. The experiment was initially run on pure diesel fuel at a constant speed of 1500 rpm. To stabilize the engine under the new conditions, the engine was run for 10 minutes at each load without data collection. This is done to ensure no fuel from earlier readings is still present in the flow meter, fuel filter, or fuel pipelines. The experiment was conducted using the basic input values for the engine settings and fuels. Eddy current dynamometer was used to record the findings under varying loads. The mentioned method was repeated under the same operational conditions for all the diesel. In this experiment, four different types of diesel were used. The Egma CG450 gas analyzer was connected to a separate sensor to evaluate the test engine's capability to emit CO, CO_2, HC, O_2, and NO_x. Table 2 details the specifications of the Egma CG450 gas analyzer. Diesel fuel is used for experimenting. Figure 2 displays the Egma CG450 gas analyzer. The NO_x (ppm), CO (% by volume), CO_2 (% by volume), and HC (ppm) emissions in the exhaust gas were measured using the Egma CG450 gas analyzer. The smoke density was measured with a Texa Smoke meter, as shown in Figure 3. A Piezoelectric pressure transducer was installed on the engine cylinder head with a sensitivity of 16.11 pc/bar and water cooling was used to measure the combustion chamber pressure. Diesel fuel was used to start the engine, and it was given time to warm up and reach normal operating temperature before being turned on. Diesel fuel was initially used to test the engine, and the findings were recorded. This procedure continues under similar operating conditions for four different types of diesel. The engine was operating at a constant speed of 1500 rpm while the steady state performance, combustion, and emission measurements were obtained four times. The average of the recorded data was then utilized to make additional calculations. For this study, four samples of diesel fuel from various refineries in Kurdistan were obtained, each with a particular set of characteristics. This practical part aims to identify the perfect diesel type. The composition and qualities of four fuels were determined in the Erbil refinery (Kar-Group), the Ministry of Natural Resources in Kurdistan-Erbil. These properties are given in Table 3. The data on emission and combustion characteristics are measured in the I.C. Laboratory at the University of Babel, College of Engineering of Al-Musaib.

Figure 1. Test engine

Table 1. Specifications of the test engine

Make	Kirloskar
Type	4 Stroke, direct injection diesel engine
Bore	87.5 mm
Stroke	110 mm
No. of cylinder	1
Connecting rod length	234
Compression ratio	15:1 ~ 18:1
Swept volume	661.5 cc
Rated power	3.5 kW @ 1500 rpm
Speed type	constant
Cooling type	Water
Compression type	VCR
Engine name	VCR diesel engine
Loading type	Eddy current dynamometer
Oil type	Multi grade SAE 15W-40

Figure 2. Exhaust gas analyzer

Figure 3. Smoke meter

Table 2. Technical specification of gas analyzer

Model	CG-450		
Measuring parameter	HC, CO, CO_2, O_2, NOx and AFR		
Method of measurement	HC, CO, CO_2: NDIR (Non-Dispersive Infrared) method O_2, NOx: Electrochemical cell		
	Range of measurement	**Resolution**	**Display type**
CO	0.00-9.99%	0.01%	4 digit 7 segment LED
CO_2	0.0-20.0%	0.1%	4 digit 7 segment LED
Lambda	0-2.000	0.001	4 digit 7 segment LED
HC	0-9999 ppm	1 ppm	4 digit 7 segment LED
O_2	0.00-25.00%	0.01%	4 digit 7 segment LED
NO_x	0-5000	1 ppm	Option
Repeatability	Less than ±2%		
Time of response	Within 10 seconds (more than 90%)		
Warming up time	About 2-8 minutes		
Sample collecting quantity	4-6 L/min		
Power	AC220V ±10% 50Hz/60Hz		
Operating temperature	-10-40℃		

Table 3. Experimental result of properties of tested fuels

Diesel	Type 1 Lanaz Refinery	Type 2 Kar Refinery	Type 3 Hawler Refinery	Type 4 Bazyan Refinery
Density @ 15℃	0.8419	0.8306	0.8434	0.8423
Viscosity @ 40℃	2.63	2.64	3.41	2.80
Flashpoint (℃)	24	61	28	49
Diesel Index	51.1	59.9	55.2	53.6

3. RESULT AND DISCUSSIONS

The results of this research include combustion characteristics such as brake thermal efficiency, brake-specific fuel consumption, EGT, carbon monoxide, carbon dioxide, unburned hydrocarbons, nitrogen oxides, and smoke opacity to determine the emission and combustion properties of the functions to assist in detecting the best type of diesel fuels. Simulated curves have been modified together with an experimental curve under various load conditions. The correlation for these emission and combustion characteristics is changed using the least square curve fitting technique with modifying factors.

The outcome of the experimental investigation on how various diesel types generated in refineries in the Kurdistan region affected exhaust emissions can be summed up as follows:

3.1 BTE

Figure 4 shows the variation in BTE for an engine running at a constant speed with a constant CR-17 under various loads. The BTEs of diesel types 2, 3, and 4 were discovered to be higher than those of diesel type 1 at low load by 8.95%, 21.36%, and 16.08%, respectively. However, compared to diesel type 1 under high load, the BTEs of diesel types 2, 3, and 4 were each increased by 7.025%, 7.42%, and 7.64%, respectively. Due to type 1 diesel's higher viscosity and lower calorific content, this outcome has occurred. The spray nature is improved when the engine load increases due to the greater cylinder temperature, which in effect, improves cylinder combustion [8]. As a result, the BTEs of diesel types 2, 3, and 4 are enhanced.

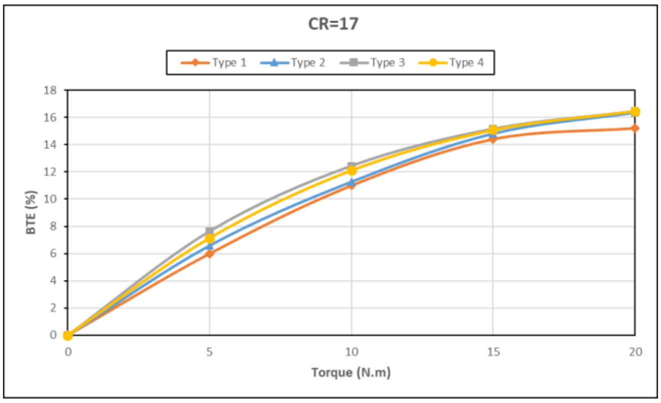

Figure 4. Brake thermal efficiency of diesel engine using different diesel fuels under various operating conditions

3.2 BSFC

An essential factor in the assessment of the diesel engine is the BSFC. The BSFCs are shown in Figure 5 under various loads. It has been discovered that diesel type 1 has a greater BSFC than other types. For instance, at low load, the BSFC of diesel type 1 is 1.2 kg/(kWh). At low load, the BSFC of diesel type 1 rises by 15% compared to diesel type 3. However, as compared to diesel type 3, the BSFCs of diesel type 2, and type 4 increased by 0.84 percent and 9.2 percent, respectively. The low calorific value of diesel is the reason for this result. The high viscosity cannot assist the fuel spray when the load is low. Diesel's oxygen content enhances cylinder combustion as engine load rises [9], minimizing the negative effects of the fuel's low calorific value.

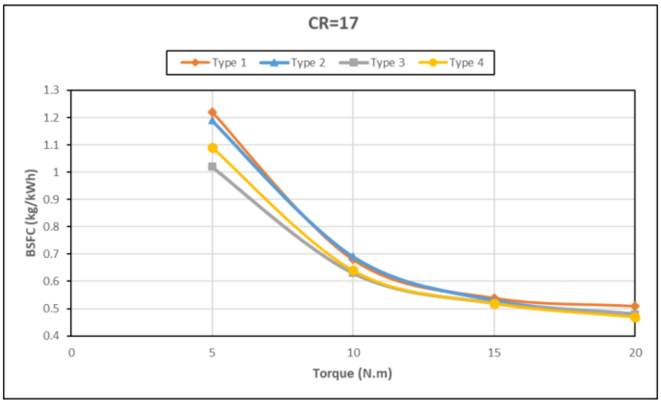

Figure 5. Dependence of Specific fuel consumption on engine load using different diesel fuels under various operating conditions

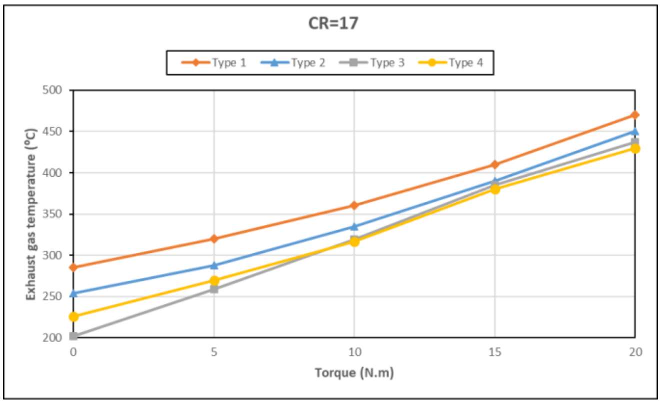

Figure 6. Comparison of exhaust gas temperature between different types of diesel fuels

3.3 EGT

A thermocouple connected to the exhaust manifold measures the impact of load on the temperature of the exhaust gas. Figure 6 illustrates that in every case, As the load increases, the temperature of the exhaust gas increases. Due to incomplete fuel combustion, this may occur inside the combustion chamber more frequently at higher than lower loads. The average kinetic energy and velocity of the gas particles contacting the cylinder walls both increase as the temperature rises. The pressure in the cylinder must rise as the temperature rises because the force generated by the particles per unit of an area determines it. Diesel type 1's exhaust gas temperature is higher than the other three modes, whereas type 3's is lower.

3.4 Carbon monoxide

Incomplete combustion of the fuel's hydrocarbons leads to carbon monoxide emissions. CO main banks exhale when an air-fuel combination is present. CO is produced during partial combustion when carbon from the fuel and oxygen are combined inside the combustion chamber. Carbon and oxygen create to form CO_2 when combustion is complete. At constant engine speed n=1500 rpm, Figure 7 depicts what the engine load does and the diesel cetane number on CO emission concentration. The outcome demonstrates that, compared to diesel type 1, emissions are decreased with increasing CN for diesel types 2, 3, and 4 by 15.7%, 47.11%, and 28.93%, respectively.

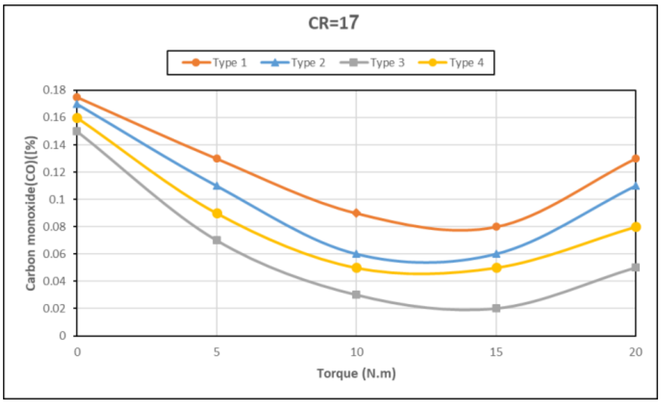

Figure 7. Variation of CO emission with engine torque for different diesel fuel at CR=17

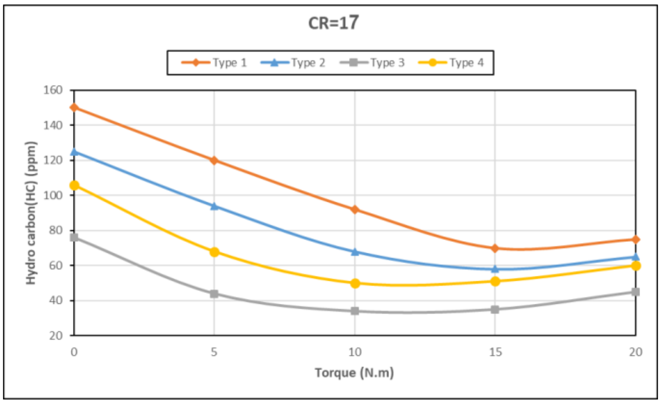

Figure 8. Variation of HC emission with engine torque for different diesel fuel at CR=17

3.5 Unburned hydrocarbon

Diesel fuel primarily consists of carbon and hydrogen. Hydrocarbon emissions occur from the partial burning of fuel inside the combustion chamber. Low flame speeds caused by a lean fuel and air mixture result in incomplete combustion or unreacted fuel, the main contributor to hydrocarbon emissions. Due to the poor atomization of the diesel fuel, the engine consumes relatively little gaseous fuel while it is running at very low loads, increased ignition delay, significant cyclic changes, and low charge temperature.

As seen in Figure 8, The amount of unburned hydrocarbon tends to decrease with increasing loads when the diesel cylinder charge has a suitable concentration. Compared to diesel type 1, diesel fuel type 3, with a cetane number of 54.9, increased fuel usage by up to 40%. Compared to diesel type 1 CN 48.8, it also decreased the amount of UBHC in the exhaust. Diesel types 2 and 4 have a slightly negative impact. Both at full loads and at very light loads, there were very few variations.

3.6 Carbon dioxide

According to Figure 9, the amount of CO_2 in exhaust emissions increases as engine torque increases and also rises as the amount of CN increases. As the engine load increases, the mass flow rate of diesel increases, which results in more fuel being burned and higher CO_2 exhaust concentrations. Higher cetane fuels burn more effectively and produce less carbon monoxide and unburned hydrocarbons, which together help to raise carbon dioxide levels in the atmosphere. So, diesel type 4 emits less CO_2, and type 1 emits more CO_2 at higher loads.

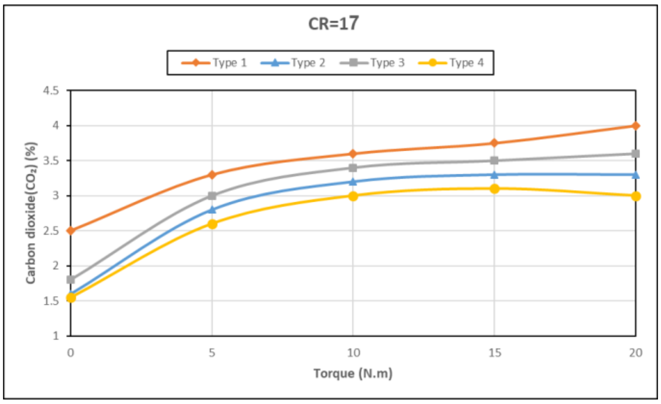

Figure 9. Variation of CO_2 emission with engine torque for different diesel fuel at CR=17

3.7 Nitrogen oxides

The higher temperature in CI engines causes bigger NO_x emission variations in NO_x emissions under different loads. In this analysis, the NO_x emission is evaluated in each mode of operation due to the observation that there is a considerable rise in NO_x emissions with loads. The NO_x emissions of the four distinct types of diesel are shown in Figure 10. Type 4 emits less NO_x than Type 1 at full load. This difference may be the result of the combustion chamber's lower and more even temperature during the combustion process, the consistent mixing of the fuel and air in the combustion chamber, the lower viscosity, and greater heat of vaporization of the diesel, which improves atomization properties and lowers the combustion. Another factor to take into account is the fact that the long ignition delay period caused a decrease in CN and increased NO_x. The increase in oxygen content raises the temperature of the cylinder. More NO_x will be produced due to the readily accessible oxygen at a higher temperature.

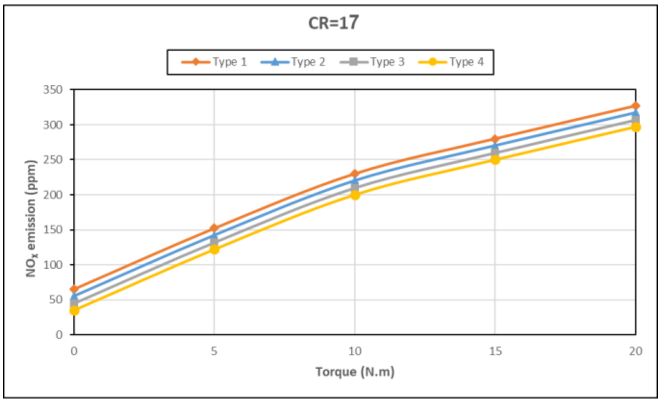

Figure 10. Variation of NOx emission with engine torque for different diesel fuel at CR=17

3.8 Smoke opacity

The amount that smoke filters out light is known as its opacity. According to this law, the smoke content of the exhaust will determine the transparency of the smoke, and vice versa. Figure 11 demonstrates that the smoke opacity of diesel type 1 is higher under all loads, whereas the smoke opacity of diesel type 3 is lower under all loads. This is because, as the engine load increases, more fuel is injected, reducing the amount of oxygen available for the reaction. Fuels that contain oxygen have a decreased tendency to produce soot. Another benefit of using diesel type 3 that reduces smoke is the reduced carbon-to-hydrogen (C/H) ratio.

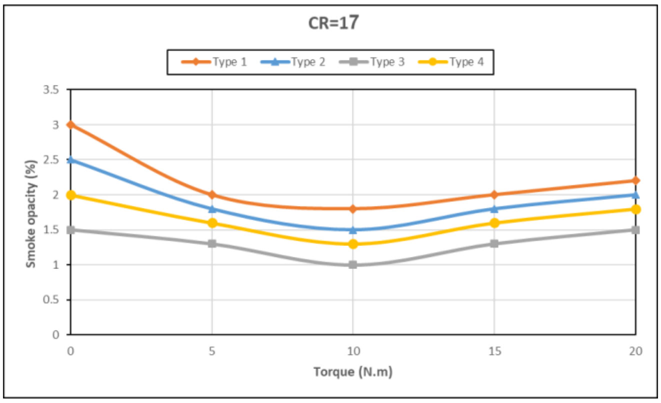

Figure 11. Variation of smoke opacity emission with engine torque for different diesel fuel at CR=17

4. CONCLUSIONS

The exhaust and combustion characteristics for four different diesel fuel types were studied on a single-cylinder, four-stroke, direct-injection diesel engine. The investigation findings are as follows:

1. At the engine's maximum brake power, diesel type 4 demonstrated the highest brake thermal efficiency of 16.48% compared to other diesel types.
2. The specific fuel consumption differed with various diesel fuels, and the result showed that diesel types 3 and 4 have less specific fuel consumption than other types of fuel.
3. The increase in the cetane number of diesel fuel has resulted in a decrease in exhaust gas temperature compared to diesel type 1, the highest exhaust gas reduction for Type 3 diesel (CN=54.9) was 13.17%.
4. With an increase in CN rating, CO emissions are reduced. When compared to diesel type 1, the highest reduction for diesel type 3 with CN=54.9 was 47.11%.
5. CO_2 emission increased with increasing fuel cetane number.
6. The investigation discovered that for all fuel types, HC emission was reduced as the load increased. Diesel types 3 and 4 emit the least amount of HC, respectively.
7. Compared to other diesel types, diesel type 1 had higher NO_x emissions.
8. Diesel types 3 and 4 were less smoke opacity and emissions, respectively.
9. Concerning fuel usage and the environment, diesel types 3 and 4 perform better than the other fuel types as primary and secondary types of diesel fuel.
10. The research results show that diesel type 3 is the best fuel produced in terms of optimal performance parameters, as well as less pollution to the environment. The concerned authorities have been informed to improve other types of fuel.

ACKNOWLEDGMENT

The authors want to express appreciation to the Department of Mechanical and Mechatronics Engineering.

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NOMENCLATURE

BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
EGT	Exhaust Gas Temperature
CO	Carbon Monoxide
(UHC)	Unburned Hydrocarbon
NO_x	Nitrogen Oxides
CN	Cetane Number