International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 4, Aug 2019, 1275–1282

ANALYSIS OF CNG-DIESEL POWERED DIESEL ENGINE COMBUSTION, PERFORMANCE AND EXHAUST EMISSION CHARACTERISTICS

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ABSTRACT

The present study investigates the performance, combustion and emission characteristics results of a 5.5 kW constant speed diesel engine, which was modified to run with both diesel and CNG fuel (diesel+CNG) under combined mode condition. The experiment was conducted with CR: 19.5:1at maximum power condition (at 1500 rpm and 5.5 kW). The brake thermal efficiency (BTE) of the engine was found lower at all different energy ratio, in comparison to diesel fuel (0% energy ratio). The deteriorations in BTE of the engine was observed at 30%, 46% and 51% of gaseous fuel energy ratio under combined mode operation. The engine powered by CNG-Diesel showed lower CO_2 and Smoke. However, it showed higher Carbon monoxide, Hydrocarbon and Nitric oxide emissions as compared to diesel fuel.

KEYWORDS: Diesel, CNG, Emissions, BTE & Diesel Engine

Received: May 15, 2019; **Accepted**: Jun 18, 2019; **Published**: Jul 29, 2019; **Paper Id.**: IJMPERDAUG2019133

Original Article

INTRODUCTION

Over the past few decades, the dependency on diesel engines has grown gradually due to the rapid growth of urbanization and industrialization. The significantly increased usage of personal and industrial vehicles increased the exhaust gas emissions into the atmosphere. These emissions contribute to climate change and global warming [1]. Due to the strict emission guidelines implementation from the government, emission regulatory organizations forced the researchers to look for alternative fuels that meet emission standards without compromising performance parameters [2]. Numerous alternatives fuels have been explored in recentyears to address the above problems. A viable alternative that has emerged from these researches is compressed natural gas, as a favorable automotive alternative fuel due to its cleaner combustion [3]. A number of studies about the diesel–CNG operating dual fuel mode have been reported in the literature. Lounici et al. [4] stated lower pressure in the cylinder under combined mode in comparison of base diesel fuel. Yasin et al. [5] informed high pressure inside the cylinder at 75% share of CNG in combined mode operation. Sunmeet et al. [6] described that the HRR is higher by 27.2% at 15% share of CNG and lower by 20.3% with 75% share of CNG in combined mode; in comparison of diesel fuel. Poompipatpong et al. [7] also described higher HRR in combined mode in comparison of single mode. Papagiannakis et al. [8] detected less rise in HRR with higher share of CNG concentration under combined mode. Sunmeet et al. [9] directed that in combined mode, the BTE increases and BSFC decreased at 4.5 kW. Singh and Maji et al. [10] also stated higher BTE at 3.5 kW under combined mode. Papagiannakis et al. [11] stated that carbon monoxide emission is lower at lower speed and higher with higher speed in combined mode. Abd et al. [12] reported that hydrocarbon emission is moderately higher in comparison of diesel fuel. Papagiannakis et al. [13] also stated high hydrocarbon emission in combined mode, due to poor combustion. Carbon dioxide emission is less in combined mode because,

with higher percentage of CNG, combined mode contains less carbon contain. Senthilraja et al. [14] also reported lower carbon dioxide emission with CNG percentage at high load. Liu et al. [15] stated less nitric oxide emission with CNG in combined mode. This is due to the lower temperature in the cylinder. Papagiannakis et al. [11] also stated less nitric oxide emission with CNG + diesel in combined mode. Mahal et al. [16] reported less nitric oxide emission with 60% under combine mode than that of base diesel fuel [17]. The smoke emission is the main problem in diesel engine. Uyehara et al. [18] stated that smoke emission generate between the range of 2000–4000 K in a diesel engine. Li Y et al. [19] stated very less smoke emission in combined mode operation. Carlucci et al. [20] also stated less smoke opacity under combined mode in comparison of base diesel. It is clear after this compressive literature review that there is a need to study about combined mode combustion.

EXPERIMENTAL SET UP

The diesel engine consists of a 4-stroke direct injection natural aspiration compression ignition engine with a nominal power of 5.5 kW at 3200 rpm, and the experiments were performed with the maximum power (5.5 kW at 3200 rpm). The engine was connected to eddy current dynamometer for charging, as shown in Figure 1. The technical specification of the engine is specified in Table 1. The test engine was modified to operate in dual fuel mode. It contains an electronic control unit (ECU), a solenoid gas injector, a pressure reduction kit and a pressure gauge. The engine was connected with the necessary instruments, such as the TDC encoder for measuring the angle of the crankshaft and a pressure transducer for the measurement of the combustion pressure.

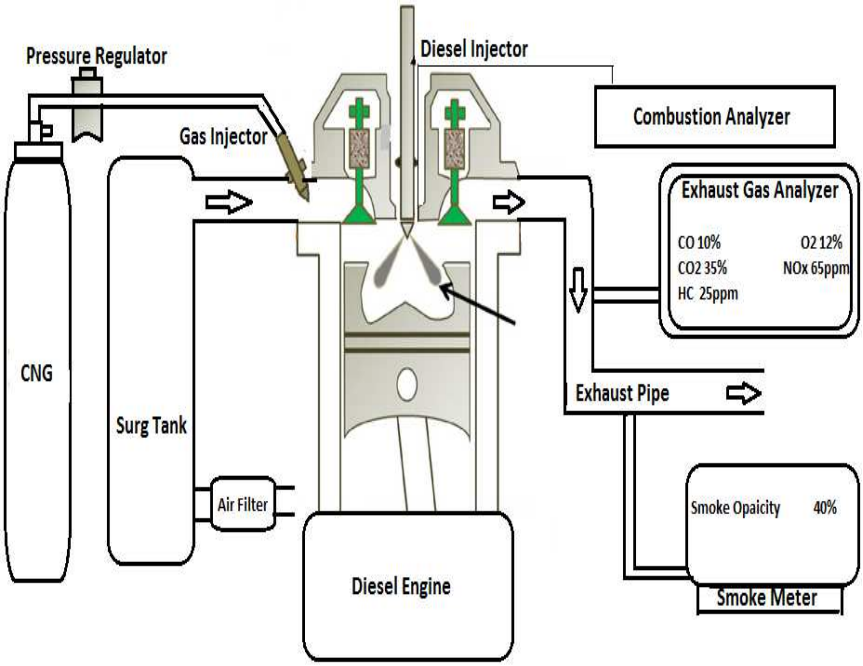

Figure 1: Experimental Setup

There are also provisions for the interconnection of air flow, fuel flow, temperatures, and load measurement. The emission data (CO, CO_2, and HC) were measured using the Di gas analyzer, based on the principle of non-dispersive infrared (NDIR). However, smoke opacity meter is used to measure the smoke emission data in terms of % opacity, which was attached to the test engine. The physical properties of diesel fuels and compressed natural gas (CNG) are shown in Tables 2 and 3.

Table 1: Test Engine Specifications [2]

Description	Parameter Values
Make and model	Kirloskar and EA10
No. of cylinders	1
Displacement Volume (cc)	947.4
Rated power output (kW)	7.4
Rated Speed (rpm)	1500
Bore (mm) x Stroke (mm)	102 x 116
Compression ratio	19.5:1

Table 2: Physico-Chemical Properties of Base Diesel [2]

Parameter	Diesel
Density (kg/m^3)	850
CV (MJ/kg)	43.97
Viscosity at 40 ^{0}C (cSt)	2.87
Flash point (^{0}C)	76
Cloud point (^{0}C)	6.5
Pour point (^{0}C)	3.1

Table 3: Physico-Chemical Properties of Base Diesel [8, 10]

Parameters	CNG
Auto-ignition temperature (K)	813
Minimum Ignition energy (mJ)	0.29
Flammability limits (vol % in air)	5–15
Density kg/m^3	0.7
Quenching gap in NTP air, cm	0.203

RESULTS AND DISCUSSIONS

In-Cylinder Pressure

It is observed from the Figure 2 that the pressure of the engine decreased slightly with 30%, 46% & 51% CNG share in combined mode. The inside pressure of the engine decreased from 68.8 bar to 64.5 bar with 0% and 51% CNG share. The inside pressure of the engine decreased with increase in CNG share. Due to the ignition delay, therefore, the in-cylinder pressure is lower than that of diesel fuel under duel fuel mode.

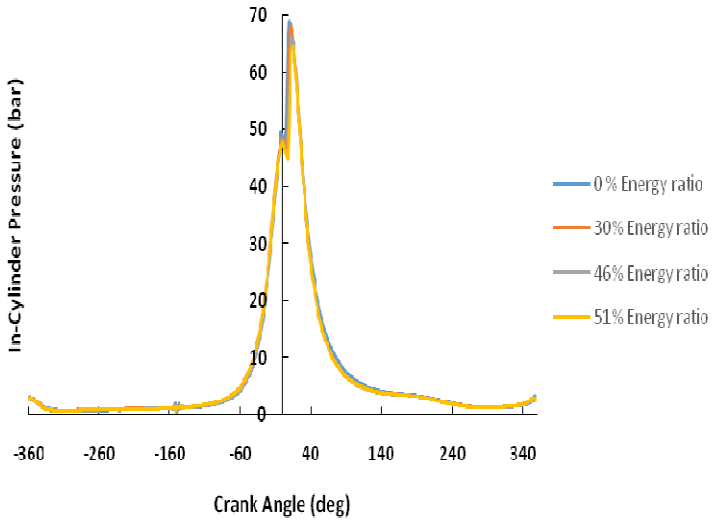

Figure 2: Comparison of In-Cylinder Pressure with Crank Angle & CNG Share

Heat Release Rate

It is observed from the Figure 3 that HRR increased slightly of the engine with 30%, 46% & 51% CNG share in combined mode. The HRR increased from 128.7 K to 130.8 K with 0% and 51% CNG share.

The HRR increased with increase in CNG share due to a larger amount of fuel is burned during the premixed combustion phase, because of maximum diesel fuel percentage that improved the combustion process.

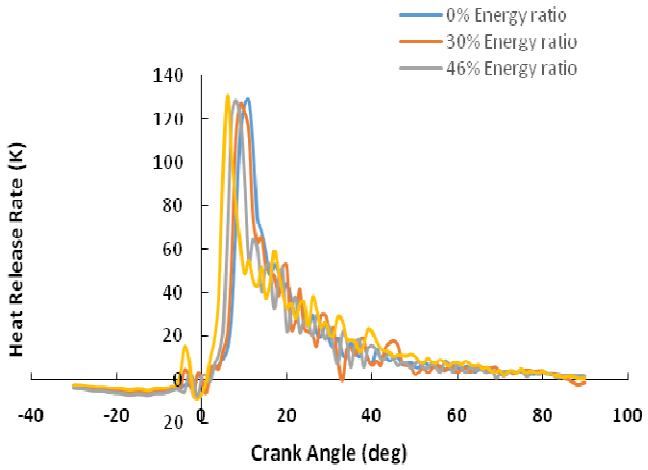

Figure 3: Comparison of Heat Release Rate with Crank Angle & CNG Share

Brake Thermal Efficiency

Figure 4 shows that the BTEincreased with 30%, 46% & 51% CNG share in combined mode. It increased from 26.6% to 26.9% with 51% CNG share. The efficiency increased because of homogeneous and constant volume combustion of both fuels during premixed combustion phase in combined mode.

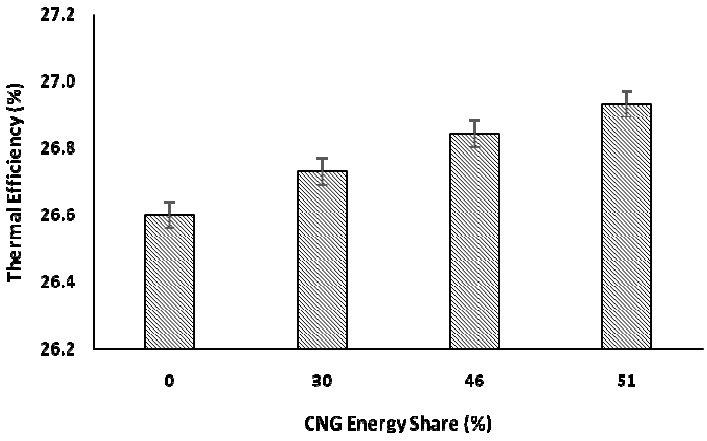

Figure 4: Comparison of BTE with CNG Share

Co Emission

It is observed from the Figure 5 that the concentration of carbon dioxide emission increased drastically with high CNG fuel share. It increased from 1.39 g/kWh to 8.9 g/kWh with a CNG share of 0% to 51% in combined mode.

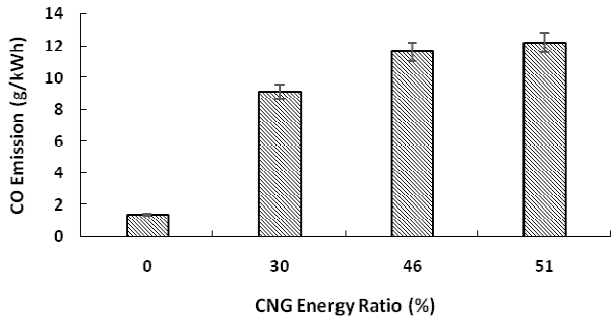

Figure 5: Comparison of CO Emission with CNG Share

It increased because of poor combustion of the CNG fuel. In combined mode operation, CNG swaps a certain amount of oxygen in the induced air, which leads to an increase in the effect of dilution of the effects, resulting in a more CO emission.

Co_2 Emission

Figure 6 shows that carbon dioxide emission decreased considerably with CNG share in combined mode. It decreased from 1060 g/kWh to 895 g/kWh with 51% CNG share in combined mode. Carbon dioxide decrease with CNG share due to a decrease in higher carbon content fuel (diesel).

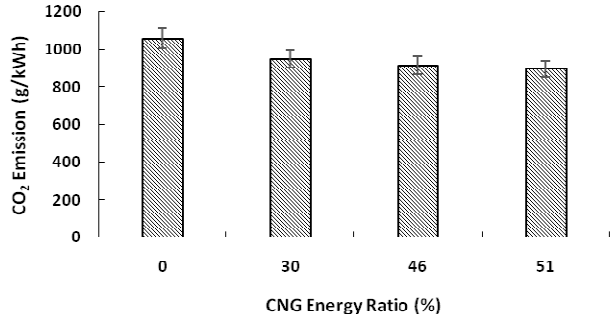

Figure 6: Comparison of CO_2 Emission with CNG Share

Hc Emission

Figure 7 shows that hydrocarbon emission increased from 0 g/kWh to 8 g/kWh with 51% CNG share in combined mode.

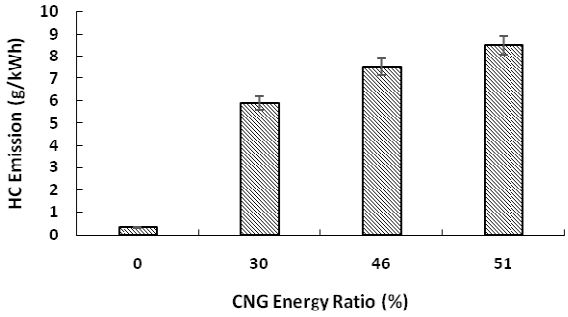

Figure 7: Comparison of HC Emission with CNG Share

Hydrocarbon emission increased with CNG share in combined mode because, when CNG energy share increased, it substitutes oxygen in the welcomed air, hence leads to reduce the flammability limits, and the flame slaked when the flame tactics the combustion chamber wall.

Nox Emission

Figure 8 shows that nitric oxide emission decreased from 14 g/kWh to 12 g/kWh with 51% CNG share in combined mode. As it is known, the NOx is a temperature dependent phenomena. It is less in combined mode with increase in CNG share, because of lower in-cylinder temperature. Because CNG reduces the quantity of air in the cylinder, it results in poor combustion, lower in-cylinder temperature and lowers NOx emission.

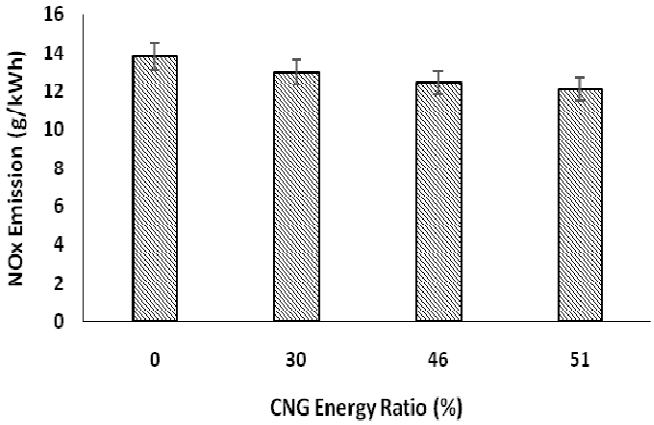

Figure 8: Comparison of NOx Emission with CNG Share

Smoke Emission

Smoke emission is formed in diesel engine due to heterogeneous nature of combustion and sulfur content in the diesel fuel. It is clearly observed from the Figure 9 that the smoke emission is less with CNG share in combined mode. It decreased from 20% to 8% with 51% CNG share in combined mode.

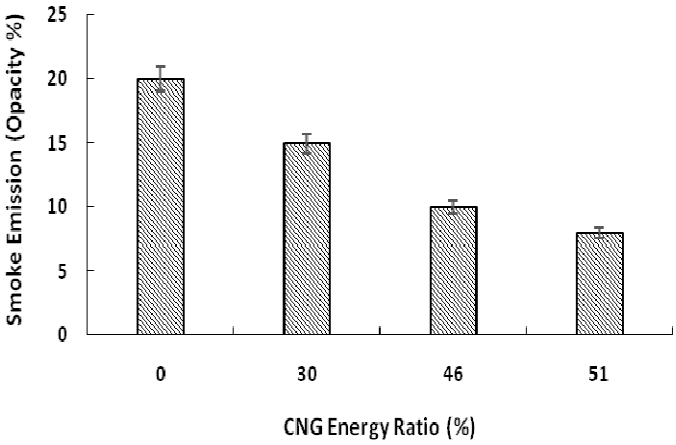

Figure 9: Comparison of Smoke Emission with CNG Share

Because CNG substitutes same amount of diesel fuel, which leads to homogeneous charge in cylinder with an increase in constant volume combustion. Therefore, standby of diesel with CNG fuel leads to a decrease in smoke emission.

CONCLUSIONS

Following are the conclusions drawn.

- BTE of the engine is marginally high with all energy shares under combined mode.
- The CO and HC emissions increased and NOx emission decreased with increase in energy share.
- The CO_2 emission decreased with CNG share under combined mode.
- The Smoke emission is less with CNG energy share under combined mode.

ACKNOWLEDGMENTS

The authors express their gratitude to the Centre for Energy Studies, Indian Institute of Technology Delhi, for providing the infrastructure to carry out the experimental work and the subsequent analyses.

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