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# Experimental investigation on performance, emission and combustion analysis of CNG-Diesel enrichment with varying injection operating pressures

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***Abstract:****CNG is one such fuel which has already been credited as a remarkable fuel in SI Engine. In the present work, Compressed Natural Gas (CNG) has been introduced as an alternative fuel to CI engine to overcome the polluting emissions and to extend the life of fossil fuels as the emission characteristics are better for CNG when compared to diesel engines [1]. In present work, experimental investigation were carried out by inducting CNG into combustion chamber in conjunction with air as CNG-Diesel dual fuel mode. Experiments were conducted on different substitution of CNG i.e. 6 LPM and 13.5 LPM at different Injection Operating Pressures (IOP) i.e. 200, 220 and 240 bar and the performance characteristics were calculated. The effect of CNG substitutions on emissions were measured at various IOPs and reported. Error analysis of uncertainty were calculated and calibrated. The peak pressure and heat release rate were also measure.*

***Keywords:****CNG, Diesel engine, Diesel, Injection Operating Pressure, Performance and exhaust emissions*

## I. Introduction

As the major source of energy comes from fossil fuels, and the prevailing fossil fuels used today by most automobiles in developing countries are petrol, diesel & gasoline. Among these, diesel is the most consumed fossil fuel which is used in compression ignition engine because of its economical nature and high thermal efficiency [2]. However, there is a sharp increase in oil consumption trend and fluctuation in international economy crisis due to simple economy model of supply and demand [3]. Apart from this, these fossil fuels are constrained and the amounts of hazardous pollution emissions such as $CO_2$, CO, $NO_x$, unburnt hydrocarbon, etc. are tremendously high. So compression ignition engine have employed alternate fuel consumption by replacing conventional fuel. CNG is one such fuel which has been used as fuel for spark ignition engine [4] and also for evolving compression ignition engine researchers as an alternative fuel. CNG resources are wide and extensive geographically and based on current consumption. The reserves are deep rooted for about 200 years. Coming to the grounds, the researchers around the world are in search of a duck soap solution for the impending problem.

## II. Experimental procedure

The experiment was conducted on a Kirloskar AV-1, single cylinder, four stroke, variable compression ratio, multi fuel, water cooled engine with dc current loading as describe in table 1, while a schematic diagram of the test rig setup is shown in Fig.1 all the experiments were carried out at full load with a constant speed of 1500 rpm. The engine had a provision to vary the compression ratio from 14.5 to 18.5. The engine instrumentation is given in Table 2. The test rig include other standard engine instrumentation, such as a thermocouple to measure oil, air, inlet manifold and exhaust temperature and pressure gauge mounted at relevant points. The combustion analysis was based on the averaged value of 100 cycles after the engine reached steady state operation. Series of several experimental cycles were conducted with varying CNG in LPM substitutions from 6 to 13.5 and iterations were done. Engine exhaust emission is measured. At each cycle, the engine was operated at varying load from 0.5 kilo Watt to 3 kilo Watts and the performance characteristics and emissions of the engine has been calculated simultaneously. The experiment is carried out by keeping the compression ratio constant i.e., 16.09:1.

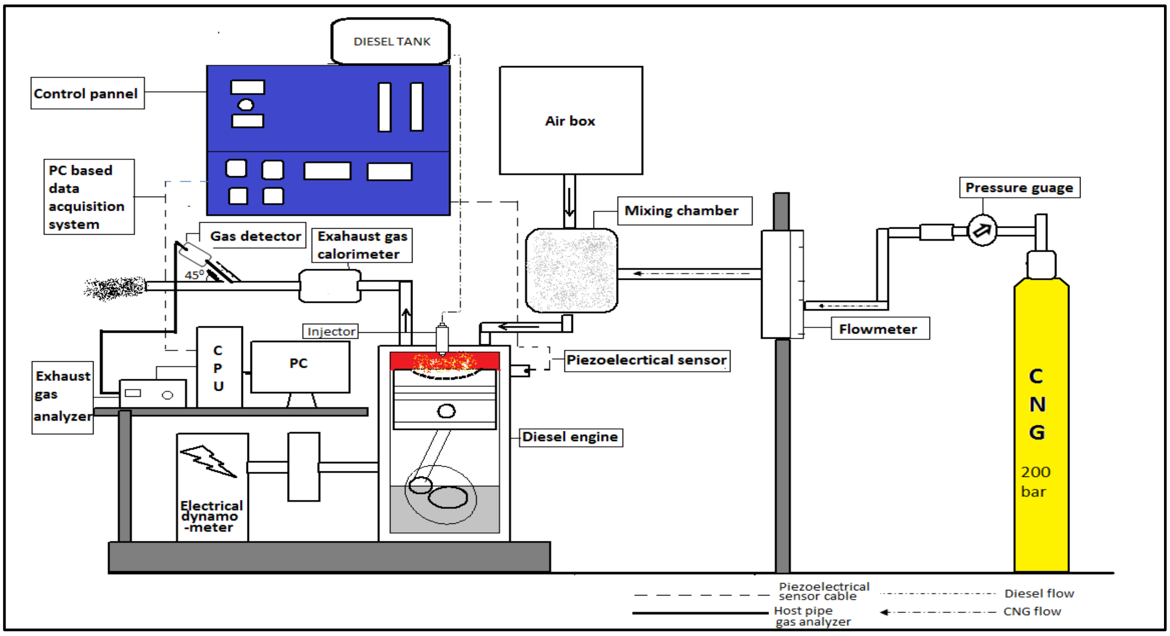

**Fig 1.** Schematic arrangement of experimental setup

**Table 1** Engine Specifications.

| **Type** | **Four- stroke, single cylinder, Compression ignition engine, with variable compression ratio** |
|---|---|
| Make | Kirloskar AV-1 |
| Rated Power | 3.7 kW, 1500 rpm |
| Bore and stroke | 80 mm x 110 mm |
| Compression ratio | 16.09 : 1, variable from 13.51 to 19.69 |
| Cylinder capacity | 553 cc |
| Dynamometer | Electrical-AC Alternator |
| Orifice diameter | 20 mm |
| Fuel | Diesel |
| Calorimeter | Exhaust gas calorimeter |
| Cooling | Water cooled engine |
| Starting | Hand cranking and auto-start also provided |

**Table 2** Properties of Compressed natural gas.

| **S.No.** | **Properties of CNG** | **Standard values** |
|---|---|---|
| 1 | Chemical formulae | $CH_4$ |
| 2 | Molecular weight | 16.03 |
| 3 | Specific gravity | 0.452 |
| 4 | Net heating value ($MJ/Nm^3$) | 43.37 |
| 5 | Ignition Temperature (°C) | 584 |
| 6 | Freezing Point (°C) | -182 |
| 7 | Boiling Point (°C) | -31.53 |
| 8 | Density ($kg/m^3$) | 126 |

## III. Error Analysis of Uncertainty

Every measurement is subject to some uncertainty. A measured result is only complete if it is accompanied by a statement of uncertainty in the measurement. Measurement uncertainties can come from measuring instrument, from the item being measured, from the environment, from the operator and from other sources. Such uncertainties can be estimated by using statistical analysis of a set of measurements and using other kind of information about the measurement process.

The measured values such as fuel time, voltage current and speed were estimated from their respective uncertainties based on normal distribution.

**Maximum error:**

$$E = Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

Where,

$z_{\alpha/2}$= Critical point

$\sigma$ = Standard deviation
n = Number of sample values

**Standard deviation:**

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Where,
$\bar{x}$ = Mean of sample
n = Number of sample values

The uncertainties in the measured parameter current (ΔI) and voltage (ΔV), estimated by Gaussian Method, are ±0.46A and ±0.4V respectively. For fuel volume (Δt), speed (Δs) the uncertainties are taken as ±2.35 & ±0.12 respectively.

To get the realistic error limits for the computed result. The principal of RMS (root mean square method) was used to get the magnitude of error as:

$$\Delta R = \sqrt{\left(\frac{\partial R}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial R}{\partial x_2}\Delta x_2\right)^2 + \cdots\left(\frac{\partial R}{\partial x_n}\Delta x_n\right)^2} \;\ldots\ldots..(1)$$

Where R is the computed result function of the independent variables $x_1$, $x_{2,}$ . . . .$x_n$ i.e., R=f($x_1$, $x_{2,}$ $x_3$, . . . . $x_n$) and $x_1+\Delta x_{1,}$ $x_2+\Delta x_2$, . . . .$x_n+\Delta x_n$ are error limits for measured variables, R+ΔR are the error limits for the computed results.

Using equation (1) the uncertainties in the computed values such as brake thermal efficiency, fuel flow and brake power measurements were estimated.

**Table 3** Instrumentations data.

| Instruments | Range | Resolution | Measurement Technique | Percentage Uncertainty |
|---|---|---|---|---|
| Voltmeter (Volts) | 0 – 750 | 1 | Absorption Type | ± 0.4 |
| Ammeter (Amps) | 0 – 20 | 0.1 | Absorption Type | ± 0.46 |
| Engine Speed Sensor (Rpm) | 0 - 5500 | 1 | TDC Pulse | ± 0.49 |
| MANOMETER (Cm) | 0 – 50 | 0.05 | Differential | ± 0.5 |
| FULE CONSUMPTION MEASUREMENT (Cm^3) | 0 - 100 | 0.5 | Volumetric Type | ± 2.35 |
| **Thermocouples** | | | | |
| Inlet Air Temperature ($T_1$°C) | 0 - 1260 | 1 | K – TYPE | ± 2.1 |
| Cooling Water Inlet Temperature ($T_2$°C) | 0 - 1260 | 1 | K – TYPE | ± 2.04 |
| Exhaust Gas Temperature ($T_3$°C) | 0 - 1260 | 1 | K – TYPE | ± 0.54 |
| Cooling Water Outlet Temperature From Engine ($T_4$°C) | 0 - 1260 | 1 | K – TYPE | ± 1.94 |
| Cooling Water Outlet Temperature Of Calorimeter ($T_5$°C) | 0 - 1260 | 1 | K – TYPE | ± 1.50 |
| Exhaust Gas Outlet Temperature ($T_6$°C) | 0 - 1260 | 1 | K – TYPE | ± 1.94 |
| **Exhaust Gas Analyzer** | | | | |
| Co % Volume | 0 - 9.99 | 0.001 | Ndir | ± 1.11 |
| $O_2$ % Volume | 0 - 25 | 0.1 | Ndir | ± 1.39 |
| $Co_2$ % Volume | 0 - 20 | 0.01 | Ndir | ± 0.88 |
| $No_x$ (PPM) | 0 - 5000 | 1 | Chemiluminescence Detector | ± 0.44 |
| UHC (Ppm) | 0 - 15000 | 1 | Flame Ionization Detector | ± 1.21 |

## IV. Results and Discussion

Experimental investigation were carried out for performance of the engine by using CNG induction. Various performance parameter and emissions graphs has been drawn to compare the behavior of CNG on various injection pressures.

### 4.1 Brake Thermal Efficiency

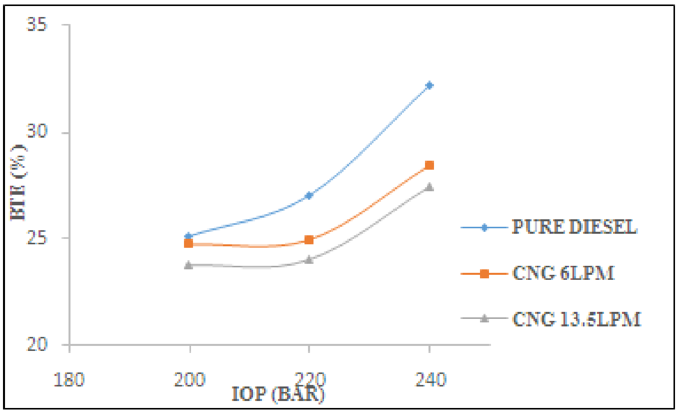

**Fig. 2** Effect of CNG substitutions on BTE at various IOPs.

Brake thermal efficiency is the measure of performance of the engine calculated as the ratio of bake power generated to the heat input. Brake thermal efficiency was calculated at various injection operating pressures (IOP) i.e. 200 bar, 220 bar and 240 bar at full load conditions at 6 and 13.5 LPM CNG substitutions. It was noticed that BTE at 200 bar is highest for pure diesel operation and then followed by CNG substitution at 6LPM and 13.5LPM as the IOP is increased the value of BTE also increased. Maximum value of BTE was observed at 240 bar for pure diesel mode i.e. 32.15% and then followed by CNG substitution 6 LPM i.e. 28.43% and for 13.5 LPM i.e. 24.43%.

### 4.2 Brake Specific Fuel Consumption

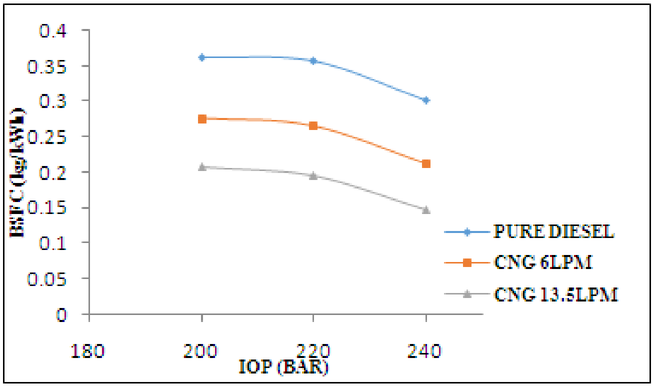

**Fig. 3**Effect of CNG substitutions on BSFC at various IOPs

Brake specific fuel consumption is the measure of quantity of fuel consumed to produce per kW of power in an hour. From the above fig. 3 it is depicted that as the IOP was increased BSFC decreases for pure diesel mode as well as CNG substitution (6 & 13.5 LPM). Highest value of BSFC was observed at 200 bar 0.363 kg/kW-h under pure diesel operation. The decreasing trend was observed as the IOP is increased.

### 4.3 Volumetric Efficiency

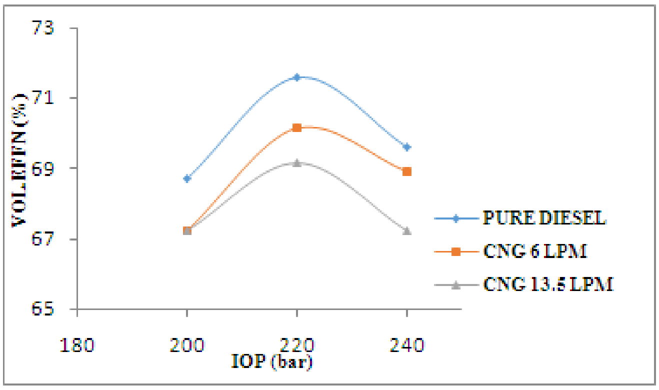

**Fig. 4** Effect of CNG substitutions on Volumetric Efficiency at various IOPs.

It has been observed from graph that as increase in CNG substitution volumetric efficiency decreased. Lowest volumetric efficiency is observe is 67.21% for 13.5 LPM CNG substitution at 240bar IOP.

## V. Emissions

### 5.1 CO Emissions

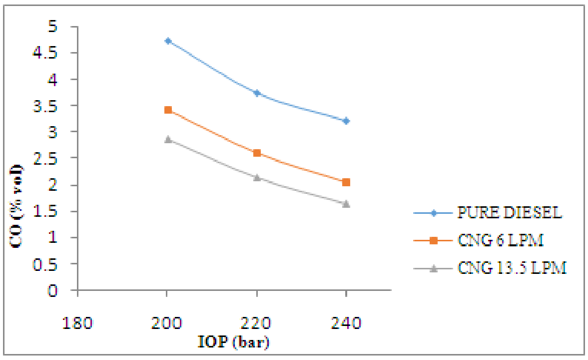

**Fig. 5** Effect of CNG substitutions on CO emissions at various IOPs.

Exhaust emission plays a significant role to predict the engine behavior. Since as noticed in the performance i.e. BTE was maximum for pure diesel operation, because of proper atomization and mixing under pure diesel mode, maximum content of CO(%vol.) was 4.435 at 200 bar, for CNG at 6 LPM and 13.5 LPM were 3.427 and 2.865 respectively. At 220 bar the CO content was decreased for all modes of operation because of uniform mixing of fuel droplets with the air. Since the BTE was lowest at 220 bar for 13.5 LPM of CNG, hence the magnitude of CO content was very low at 220 bar for the same substitution i.e. 1.417.

### 5.2 $CO_2$ Emissions

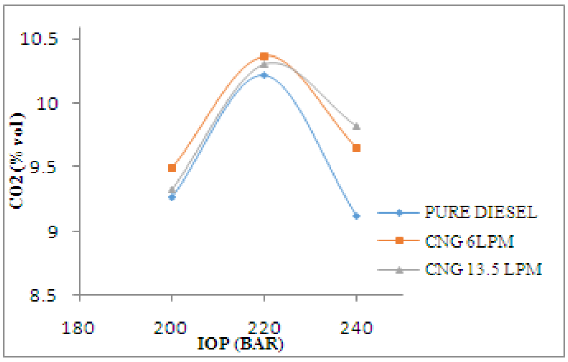

**Fig. 6** Effect of CNG substitutions on $CO_2$ emissions at various IOPs.

The above fig. 6 shows the effect of IOP on $CO_2$ .since the BTE under pure diesel mode was maximum and hence the formation of $CO_2$ decreased for pure diesel .Maximum value of $CO_2$ was observed at 220 bar when the engine was operating at 6 LPM i.e.10.37, followed by the 13.5 LPM and then for pure diesel.as the IOP increased up to 240 bar the $CO_2$ content decreased. Low content of $CO_2$ under pure diesel operation reveals that as the BTE increases the formation of $CO_2$ decreases.

### 5.3 $NO_x$ Emissions

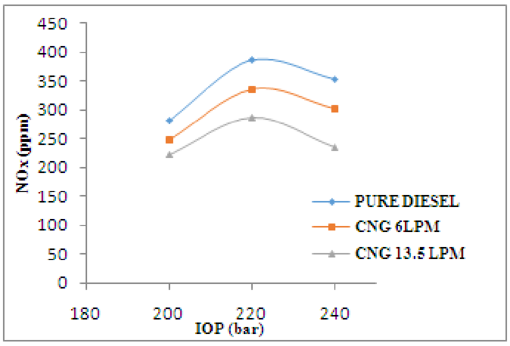

**Fig. 7** Effect of CNG substitutions on $NO_x$ emissions at various IOPs.

The above fig. 7 depicts the behavior of NOx with respective to the IOPs. The cylinder pressure was maximum under pure diesel mode compared to different CNG substitutions because of homogeneous atomization as well as proper mixing of fuel particles with the air, causes complete combustion. When the cylinder pressure was high the formation of NOx were maximum, as shown for pure diesel mode, followed by 6LPM and 13.5 LPM respectively. The highest value of NOx was observed for diesel at 220 bar.

### 5.4 Unburnt Hydrocarbon Emissions

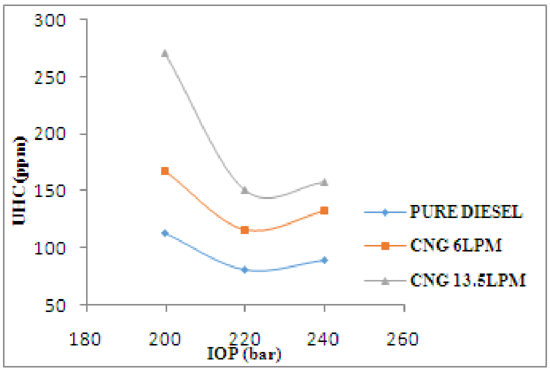

**Fig. 8** Effect of CNG substitutions on UHC emissions at various IOPs.

The formation of UHC inside the engine cylinder and top of the piston head and across the piston rings was due to incomplete combustion. From the above graph it was noticed that maximum magnitude of UHC were observed at 200 bar with 13.5 LPM of CNG substitution i.e., 271 ppm. As the IOP was increased up to 220 bar homogeneous mixing will take place, causes to increase the BTE and results in low content of UHC for all substitutions.

## VI. Rate of Heat Release (ROHR)

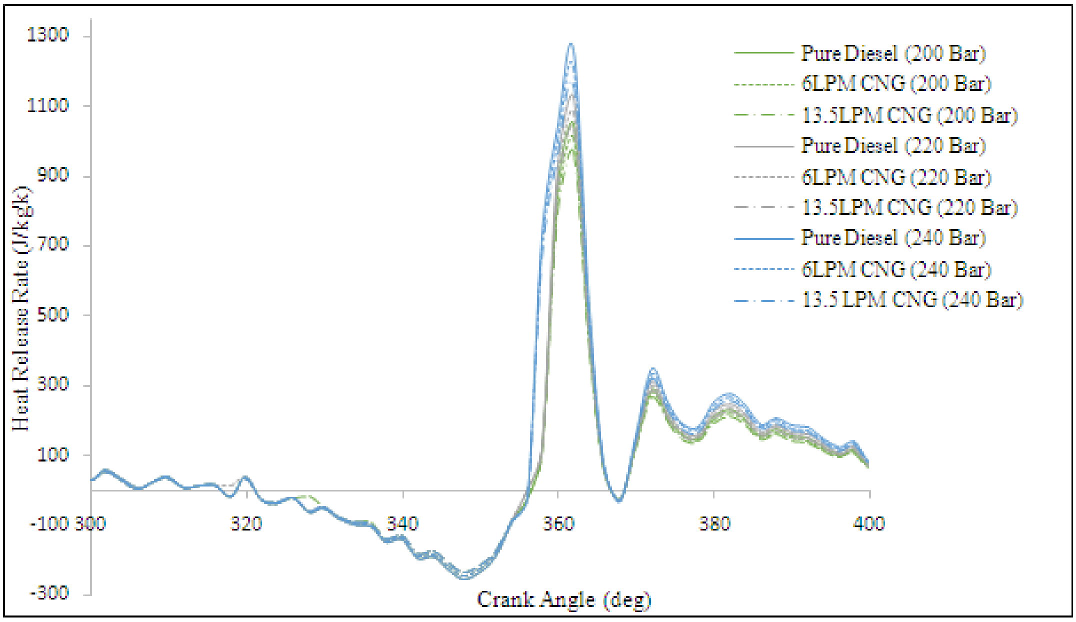

**Fig. 9** Effect of CNG substitutions on HRR emissions at various IOPs.

Above Figure 9 shows the rate of heat release per degree of crank angle at full load for different substitution of CNG ratios. In this operation the peak heat release was found at $362^{o}$ crank angle and at pure diesel operation. The peak heat release rate for dual mode at 6LPMCNG substitution was 1208.89 J/deg and 1258.74 J/deg for pure diesel operation. The peak heat release is more in case of pure diesel at 240bar IOP this is due to fine atomization of fuel for fluent combustion.

## VII. Conclusions

- As injection operating pressures increased BTE has also increased and as the CNG substitution increased BTE decreased.
- As injection operation pressure increased BSFC decreased and the same effect shown on CNG substitution also.
- Increase in CNG substitution volumetric efficiency decreased.
- As the injection operating pressure increased CO emissions decreased for all the operations. CO emissions has also decreased as the CNG substitutions increased
- As the injection operating pressure increased $CO_2$ emissions increased at 220 bar and thereby decreased at 240 bar for all the operations.
- $CO_2$ emissions has also increased when compared with pure diesel operation and CNG substitutions operation but decreased as the CNG substitution increased.
- As the injection operating pressure increased $NO_x$ emissions increased at 220 bar and thereby decreased at 240 bar IOP. $NO_x$ emissions has also decreased by increasing CNG substitution.
- As the injection operating pressure increased UHC emissions decreased at 220 bar thereby slightly increased at 240 bar but for pure diesel operation it decreased continuously. UHC emissions were increased by increasing CNG substitution.
- In this operation the peak heat release was found at $362^o$ crank angle and at pure diesel operation. The peak heat release rate for dual mode at 6LPM CNG substitution was 1208.89 J/deg and 1258.74 J/deg for pure diesel operation.
- The peak heat release is more in case of pure diesel at 240bar IOP this is due to fine atomization of fuel for fluent combustion.

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