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EXPERIMENTAL INVESTIGATION OF GASEOUS EMISSIONS AND PARTICLE NUMBER (PN) CHARACTERISTICS FOR CNG HEAVY DUTY ENGINES

Bhavesh Sheth
Mechanical Engineering
Savitribai Phule Pune university
Pune, India
bhave1sheth78@gmail.com

ABSTRACT

This study deals with the investigation of the various gaseous emissions and characteristics of particle number of CNG fuelled heavy-duty engines. The introduction of the Bharat Stage-VI (BS-VI) emission norms has also challenged the automobile manufacturers to come up with innovative ideas, for reducing the gaseous emissions from a conventional internal combustion vehicle. Thus, the various parameters are studied to control and monitor the effects of varying load conditions, of the CNG fuelled engine. The study shows the variation in the emission of exhaust gases and particle numbers at two different parameters. Two testes were carried out on a CNG engine in which the exhaust gases and PN characteristics were observed and best suitable method is suggested.

Keywords: Bharat-stage VI (BS-VI), CNG, Heavy duty vehicles, Particle number (PN)

1. Introduction

Due to continuous technological development in all fields of industry it is necessary to reduce its negative impact on the environment. The use of advance techniques and technological developments obliged to continuously verify the working conditions of the machineries and equipments to analyze their impact on the environment and human society. The automotive industry is dynamic in nature and developing branch; therefore, it is necessary to reduce its harmful emissions of gas components. The emission of Particulates is the most utmost threat to the humans, and it is also a barrier to the development to the modern internal combustion engines, especially engines with direct fuel injection. An important challenge faced by an automotive manufacturer is, subsequent projects on toxicity standards, according to which the emissions of the Particulate Matter (PM) should be lower than the current levels. Compressed natural gas (CNG) vehicles operate much like gasoline-powered vehicles with spark-ignited Internal Combustion (IC) engines. The engine functions the same way as a gasoline engine. Natural gas is stored in a fuel tank typically a cylinder, at the back of the vehicle. A CNG fuel system carries high-pressure Compressed Natural Gas from the fuel tank to the engine's intake manifold or combustion chamber. The high pressure of the CNG fuel is then reduced to a level compatible with the fuel injection system, and the fuel is then introduced into the intake manifold or directly into combustion chamber, where it is mixed with air. The fuel-air mixture is then compressed to combustion temperature and then this high-pressure high temperature air-fuel mixture is then ignited by a spark plug.

However, CNG has some advantages compared to gasoline and diesel from an environmental perspective. It is a cleaner fuel than either gasoline or diesel as far as emissions are concerned. Compressed natural gas is considered to be an environmentally clean alternative to those fuels. Normally more than 90% of natural gas is methane but, that in the natural gas composition more than 98% is methane.[1]

Composition of natural gas is given in the following **(Ref Table1).:**

Engine Concepts for CNG application[2], describes advance engine concepts and potentials linked to CNG fuel and for bi-fuel (CNG/ gasoline) power trains, variable compression ratio. It also evaluates fuel economy and emission levels from lean burn of CNG.

The main impulse for realizing importance of CNG powertrains lies in the emission of CO_2 gas of a vehicle which is 25% lower than with gasoline for the same efficiency. Better efficiency and greater knock tolerance is also a main reason to choose CNG as fuel. On current CNG engines, this is an advantage of about 3 to 6%. Further, to study the performance of a mono-fuel six cylinder inline CNG engine was investigated under real world conditions[3].

2. Bharat stage Emission norms for heavy-duty vehicles

Bharat Stage Emission Standards (BSES) are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion engines and Spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment, Forest and Climate Change.

Although norms help in bringing down pollution level significantly, it also results in increased cost of vehicles due to improved technology and higher fuel prices. However, this increase in private cost is aligned by savings in health costs for the public, as there is a lesser amount of disease-causing Particulate Matter and pollution in the air. Air pollution causes respiratory and cardiovascular diseases, which is estimated to be the cause for 620,000 early deaths in 2010, and the health cost of air pollution in India has been assessed at 3% of its GDP.[5]

BS-VI norms are: **(Ref Table-2) & (Figure-1)**

3. Test setup

Three major components of the test cell are engine, dynamometer (in this test electrical dynamometer have been used) and control console. Four stroke six-cylinder CNG engine is used. The Electronic Control Unit (ECU) maintained the air-fuel ratio close to stoichiometric conditions at all times, by monitoring the signal received from the O2 sensor in the exhaust manifold. The ECU has controlled the duty-cycle of the fuel metering solenoid valve, thereby regulating the supply of CNG from the gas regulator to the injector. The flow rate of CNG and the instantaneous pressure depend on the engine vacuum applied to one side of the diaphragm of the gas regulator. The engine vacuum is proportional to the load on the engine. To run the engine at normal temperature coolant is supplied through an external pump. Engine crank shaft is attached directly to the electrical dynamometer to measure the engine output parameters. For the cooling of the dynamometer forced air circulation is done in the area of the dynamometer. This dynamometer then showed the reading to the output monitor. This whole system is monitored via computer systems. Different types of sensors are used and attached into the exhaust tunnel to measure emission of the different gases from exhaust. (Ref Table – 3)

4. Result

There were two types of tests carried out. In the first test torque is kept constant at various lambda conditions and emission readings were taken. In another test, lambda is kept constant at various torque condition. Lambda is nothing but the ratio of actual air-fuel ratio to the stoichiometric air-fuel ratio. The outcome of the first test is represented in the table 4. Similarly, table 5 represents data for the test where torque is kept constant. The equation from the graph shows that for the corresponding value of x, value of y can be found. (Ref Table – 4)

4.1. For table 4

Result graphs for table 4 are plotted against variable values of lambda to the particular exhaust gas. These are as follows: **(Ref Figure – 2)**

As increase in value of lambda, cylinder temperature increases. When N2 and O2 combine at higher temperatures oxides of nitrogen are formed so emission of NOx increases. **(Ref Figure – 3)**

For the higher value of lambda, cylinder temperature increases. At higher temperature complete combustion of fuel occurs hence emission of total hydrocarbons (THCs) reduces. **(Ref Figure – 4)**

CO is produced by incomplete combustion of fuel, generally caused by insufficient oxygen or by dissociation of gases at high temperature. For the higher value of lambda, cylinder temperature increases causing complete combustion. Hence emission of carbon monoxide reduces. **(Ref Figure – 5)**

For this particular test, the number of PN concentrations increases as the value of lambda is increased but decreases significantly for further increase in lambda at constant torque condition.

4.2. For table 5

Result graphs for table 5 are plotted against variable values of torque to the particular exhaust gas. These are as follows:

At constant lambda, when torque is increased, cylinder temperature decreases. Oxides of Nitrogen are formed only when N2 and O2 combines at high temperatures.

But, in this case due to lower temperature emission of NOx decreases. **(Ref Figure- 6)**

At constant lambda, when torque is increased, cylinder temperature decreases causing incomplete combustion of fuel producing more total hydrocarbon (THCs) emission. **(Ref Figure- 7)**

CO is produced by incomplete combustion of fuel, generally caused by insufficient oxygen or by dissociation of gases at high temperature. At the constant value of lambda, when torque is increased, due to lack of oxygen incomplete combustion occurs resulting in increased emission of Carbon Monoxide. **(Ref Figure- 8)**

For this particular test, the number of PN concentrations increases as the torque is increased at constant value of lambda condition. **(Ref Figure- 9)**

5. Conclusion

In this paper, experimental investigation of gaseous emissions and particle number (PN) characteristics for CNG heavy duty vehicles have been described. Experiment carried out on two major criteria. In table 4; data is obtained by keeping torque constant and table 5 is obtained by keeping lambda constant throughout the test and results are plotted on the graphs. Final conclusion is as follows:

From this experiment it is concluded that when torque is constant and lambda is variable engine produces comparatively less THCs and CO. Apart from that amount of emission of PN is also less for certain volume of exhaust. But in actual practice it is impossible to keep torque constant. Hence, we must adjust the value of lambda according to variable torque range. As CNG engine works on stoichiometric air-fuel ratio, at higher torque, adjusting lambda in such a way that emission is lower i.e., lambda should be on the richer side when high torque is required but emission should be minimal and for lower-load and part-load condition keeping lambda near to the stoichiometric value is effective.

6. References

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[3] Real-World Performance of a CNG Heavy Duty Articulated Truck, 2011-24-0192; Luis Cachon and Ernst Pucher.
[4] INDIAN EMISSIONS REGULATIONS Limits, Regulations, Measurement of Exhaust Emissions and Calculation of Fuel Consumption, Mrs Rashmi Urdhwareshe Director-ARAI.

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Table 1 Composition of natural gas

Sr. No.	Fuel Properties	CNG
1	Formula	CH4
2	Octane No. (MON)	120
3	Stoichiometric A/F ratio	17.2:1
Composition (%w/w)		
4	Carbon	75
5	Hydrogen	25
6	Oxygen	0
7	Density (kg/m^3)	G=0.72
8	Freezing point (deg. Celsius)	-182
9	Boiling point (deg. Celsius)	-162
10	Auto ignition Temp (deg. Celsius)	540
11	Flash point (deg. Celsius)	-104
12	Lower heating value (Kcal/kg)	12500
13	LHV of stoichiometric mixture	2.62
14	Adiabatic Flame Temp (deg. Celsius)	2770
15	Wobbe index (MJ/Nm^3)	51

Table 2 BS-VI norms[5]

	CO (Mg/kWh)	*CH4 (Mg/kWh)*	*NOx (Mg/kWh)*	*NH3 (ppm)*	*PM mass (Mg/kWh)*	*PN No. (Number/kWh)*
WHTC (PI)	*4000*	*500*	*460*	*10*	*10*	$6*10^{11}$

3.1 Experimental data

3.1.1 Engine specification

Table 3 Engine Specifications

No. of Cylinders	6
Fuel	CNG
Fuel Injection type	MPFI
Engine Fly up RPM	2550
Application	CNG heavy duty vehicle engine

3.1.2 Gaseous emissions

Table 4 emission at constant torque

Sr. no	Speed	Torque	Fuel Flow	a/f ratio	Lambda (λ)	NOx	THC	HIGHCO
	RPM	NM	Kg/hr	Kg/hr	-	PPM	PPM	PPM
1	2000	352.89	15.54	253.51	0.948	6.9	229.3	3344.4
2	2000	352.89	14.73	253.51	1.001	8.2	218.7	3215.8
3	2000	352.89	14.04	253.51	1.050	12.1	204.6	2990.7

Table 5 emission at constant Lambda

Sr. no	Speed	Torque	Fuel Flow	a/f ratio	Lambda (λ)	NOx	THC	HIGHCO
	RPM	NM	Kg/hr	Kg/hr	-	PPM	PPM	PPM
1	2000	211.73	12.23	210.42	1.001	16.4	164.0	2411.8
2	2000	282.31	13.26	228.16	1.001	12.4	185.9	2733.4
3	2000	352.89	14.73	253.51	1.001	8.2	218.7	3215.8

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Figure 1- Test cell with transient electric dynamometer layout

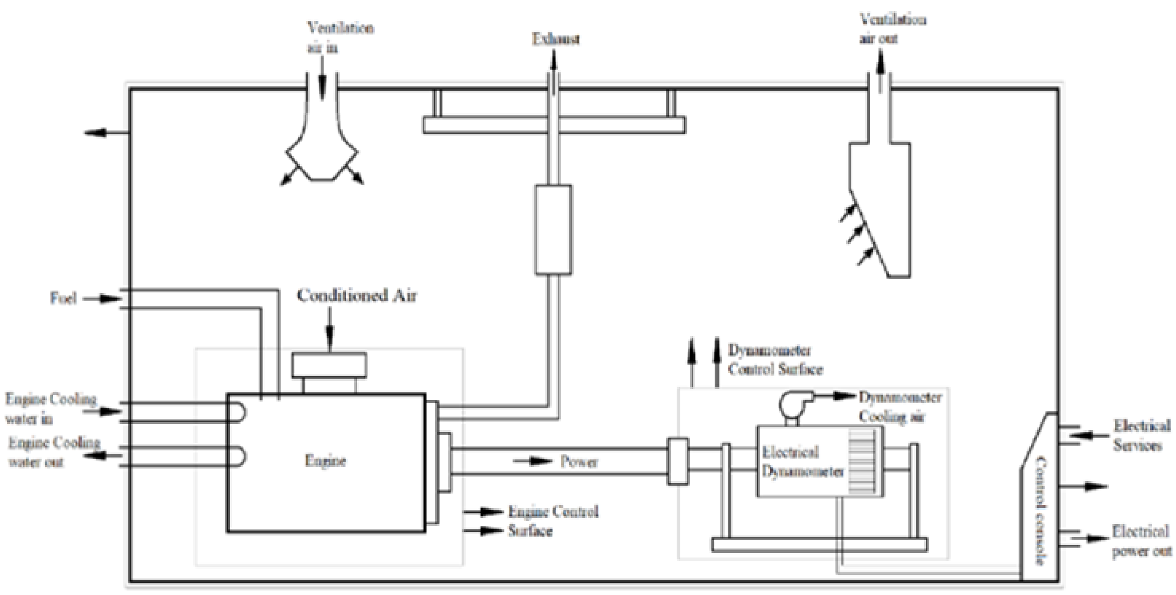

Figure 2 Lambda vs NOx

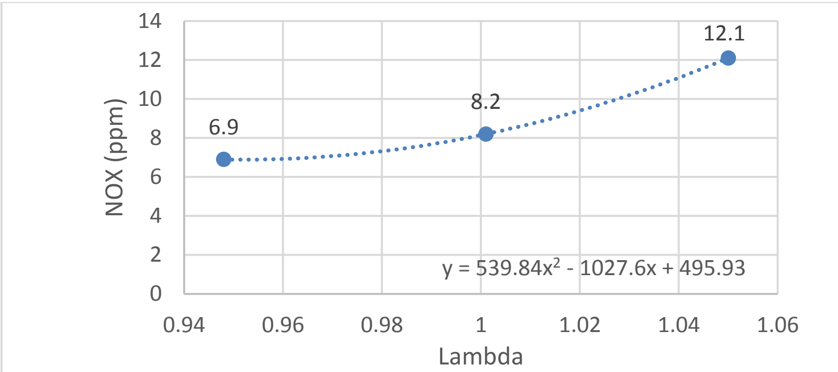

Figure 3 Lambda vs THC

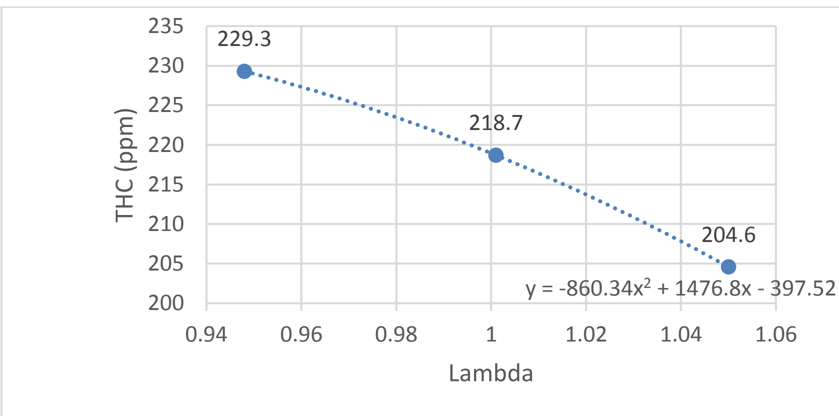

Figure 4 Lambda vs CO

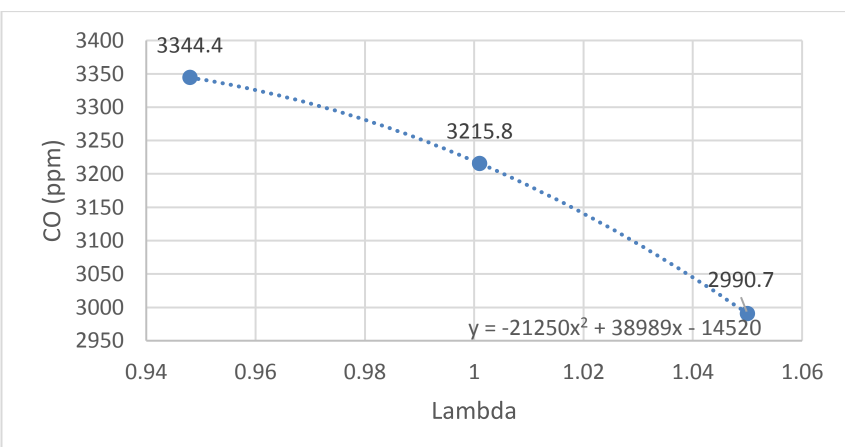

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Figure 5 Lambda vs PN

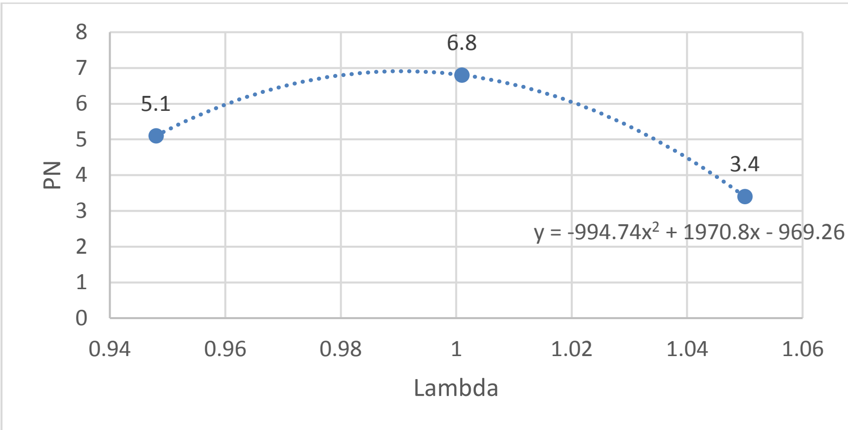

Figure 6 Torque vs NOx

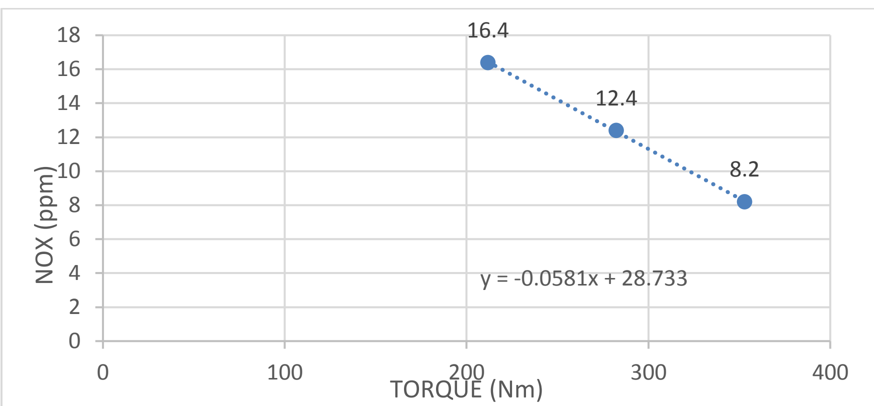

Figure 7 Torque vs THC

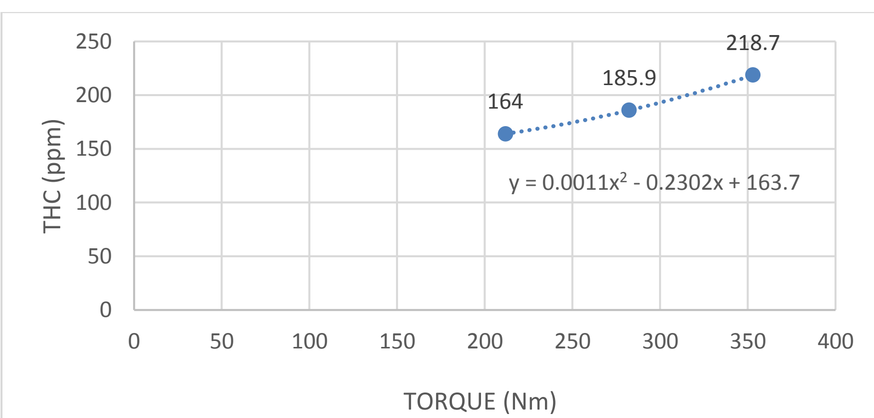

Figure 8 Torque vs CO

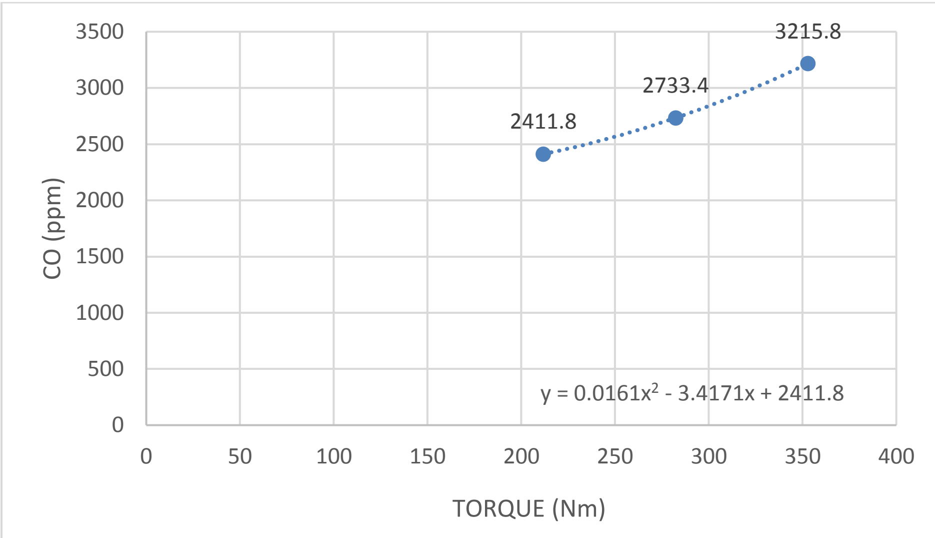

Figure 9 Torque vs PN