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Investigations on Performance of Four Cylinder Turbo Charged Engine with BS6 Emissions

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ABSTRACT—India was following BS IV norms that was adopted across the country. Bharat Stage VI norms includes a wide list of technological modifications under the hood, the most significant being making On-board diagnostics mandatory for all vehicles. As the emission standards were tightened, more advanced management methods were applied that enclosed modifications in engine design and equipment, management of engine parameters and use of exhaust after treatment devices. Reduction of toxic substances emission from combustion engines will be achieved by primary (inside engine) measure and secondary (outside engine) measures. To fulfil the specified demand, the alternative fuels utilized in petrol and diesel engines have become the topics of interest nowadays. For this reason, natural gas is employed as another fuel. This work analyses emissions from 107 kW port injection, turbocharged inline four cylinder 4 stroke natural gas heavy duty engine. Heavy-duty engines are type approved on engine dynamometers.

KEYWORDS: Catalytic Convertor; emissions; exhaust; norms; pollution

I. INTRODUCTION

Bharat stage emission standards 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 & Forests and climate change.

The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with the regulations. Since October 2010**,** Bharat Stage (BS) III norms have been enforced across the country. In 13 major cities, Bharat Stage IV emission norms have been in place since April 2010 and it has been enforced for entire country since April 2017. In 2016, the Indian government announced that the country would skip the BS-V norms altogether and adopt BS-VI norms by 2020. In its recent judgment, the Supreme Court has banned the sale and registration of motor vehicles conforming to the emission standard Bharat Stage-IV in the entire country from April 1, 2020.[1]

On November 15, 2017 The Petroleum Ministry of India in consultation with Public Oil Marketing Companies decided to bring forward the date of BS-VI grade auto fuels in NCT of Delhi with effect from April 1, 2018 instead of April 1, 2020. In fact, Petroleum Ministry OMCs were asked to examine the possibility of introduction of BS-VI auto fuels in the whole of NCR area from April 1, 2019. This huge step was taken due the heavy problem of air pollution faced by Delhi which became worse around this year. The decision was met with disarray by the automobile companies as they had planned the development according to roadmap for 2020. While the norms help in bringing down pollution levels, it invariably results in increased vehicle cost due to the improved technology & higher fuel prices. However, this increase in private cost is offset by savings in health costs for the public, as there is lesser amount of disease causing particulate matter and pollution in the air. Exposure to air pollution can lead to respiratory and cardiovascular diseases, which is estimated to be the cause for 6.2 lakh early deaths in 2010, and the health cost of air pollution in India has been assessed at 3% of its GDP.

II. CATALYTIC CONVERTER

Toxic Emissions from engine is converted into less toxic emission in a catalytic converter which is an after treatment device. The change in exhaust gas is due to redox reaction in catalytic converter. The core material is ceramic which is substrate used for automobile catalytic converter and it has

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honeycomb structure. Main purpose to use honeycomb structure is to provide larger surface area. The transporter for the catalytic resources is washcoat and is utilized to scatter the supplies over a huge surface area. Aluminium oxide, silicon dioxide, titanium dioxide, or a mixture of silica and alumina can be used. Due to higher cost, platinum is rarely used. Mostly Rhodium and palladium is used. These are used as catalyst. For oxidation, palladium is used and for reduction catalyst Rhodium is used. For both processes of reduction and oxidation platinum can be used. [2]

III. METHODOLOGY

The main objective is to investigate the performance and emissions of engine when BS6 catalytic converter is used

- Experimental setup for laboratory testing
- To conduct experiment on engine testing bed with type approved CNG engine using catalytic converter
- Analyze the data collected.
- Observation & conclusion

IV. EXPERIMENTAL SETUP

The engine is also attached with the various analyzers, arranged as shown below and the data is analyzed by the software. The engine is coupled with dynamometer and the test is carried out. The ECU manages various parameters. The input parameters are given to dynamometer and the engine is run on predetermined mapped values.

A. Engine Dynamometer.

Dynamometer is used to run the engine mounted to it. The engine speed and the load (torque) applied to the engine is varied by various input parameters given to the dynamometer. The engine behavior at different loads can be analyzed with the help of dynamometer. [3]

B. Fuel Circuit

It consists of four instruments: cylinder for compressed natural gas, fuel line, high pressure regulator and fuel meter. CNG cylinder is used to store fuel for the engine testing. Fuel line is used to transfer fuel from the cylinder to the engine's fuel injection system. High pressure regulator is used to reduce and regulate the pressure of the fuel exiting the cylinder, lowering it to an acceptable level required by the engine's fuel injection system. Fuel meter is used to measure the amount of fuel used/injected in the engine. From the values of the fuel consumption, the efficiency of the engine can be measured. [4]

C. Coolant and Oil Conditioning System

This coolant conditioning system is used to regulate the engine temperature. From the values of the coolant temperature at various points in the engine, the efficiency of the engine cooling and the errors in it can be obtained. The oil conditioning system maintains the lubricant level in the engine. The quality and quantity of the oil circulated the engine is continuously monitored and the engine performance is analysed by it.

D. Gas Analyzer

It is used to measure the emission of the engine. The values of various exhaust gases indicate the engine performance and necessary parameters can be changed in order to attain the required emission and engine performance.

Measurement of Carbon Monoxide Emissions

The exhaust gas sample are trapped immediately after the exhaust port and passed through a cold trap to remove moisture. A non-dispersive infrared (NDIR) analyzer is used for this purpose. The concentration of carbon monoxide is measured in percent volume basis with respect to dry exhaust. The analyzer is frequently calibrated with a standard gas.

Measurement of Unburned Hydrocarbon Emissions

A non-dispersive infrared (NDIR) analyser is used for measuring HC emission levels in the dry exhaust gas. The HC is measured in equivalent of methane. The HC analyser is calibrated periodically using standard calibration gas.

Measurement of NO Emissions

Nitric oxides (NO) emission in the exhaust gas is measured with a chemical sensor used in di-gas analyser. It works on the principle that when chemical comes in the contact with gas being measured, its property is changed. [5]

Table 1 Specifications of Engine

Cubic Capacity of Engine	3800cc
No. of cylinders	4
Bore	105mm
Stroke	112mm
Power	107KW
Torque	430Nm
Idle rpm	700

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Type	Turbocharged SI engine
Fuel Used	Compressed natural gas

a.

Table 2 Specifications of Dynamometer

Dynamometer type	Eddy Current
Max. speed	5600 rpm
Torque	1200Nm
Power	250KW
Voltage	400v

Table 3 Specifications of Catalytic Converter

Type	Three way Catalytic Converter
Volume	4 Liters
Substrate Type	Ceramic
Manufacturing Process	Metal Canning
Loading Pt:Pd:Rh	0:10:2
Cell Density	600cpsi

V. EXPERIMENTION

A. Experimentation Procedure

The engine used for this experiment is a four cylinder four stroke single point port injection spark ignition engine. The engine crankshaft was coupled to an eddy current dynamometer to provide brake torque and it was fitted with the suitable instrumentations for control and measures the operating parameters. The engine uses Compressed Natural Gas (CNG) as a fuel during the experiments. The engine was run until it reached steady state. The exhaust from the engine is passed through catalytic converter and then passed through exhaust gas analyzer. Lambda sensor is placed before and after catalytic converter to check for oxygen quantity in exhaust. Two thermocouples placed in the exhaust pipe and in the air intake chamber were used to measure numerous exhaust gas temperatures and air intake temperatures. The initial conditions/parameters of engine like intake manifold pressure, fuel flow, engine speed etc. are set and the engine is cranked. After the readings from the various parameters and analyzers are stable, the output parameters like engine power, torque, emissions, lambda, emissions etc. are noted. Then, the engine is run on predefined WHTC test cycle and the reading are analyzed.

For testing the engine, two methods are used.

i) Constant load and varying speed

In this method, the engine is subjected to constant load and the engine speed is changed having predetermined intervals. The various parameters like Brake Power, Torque, BSFC, THC, CO, NOx are measured. It is further carried out with other loads and the data is analyzed.

ii) Constant speed and varying load

In this method, the engine is set at constant speed and the load is changed viz. 25%, 50%, 75% and Full load. The various parameters like Brake Power, Torque, BSFC, THC, CO, NOx are measured.

B. Experimental Test Cycle

Worldwide Harmonized Transient Cycle (WHTC) is specifically developed to be more representative of real world driving, and includes a much higher percentage of low speed and low load conditions. The use of the WHTC forces makers to use NOx reductions strategies such as engine calibration, thermal management, lean NOx trap, and others that operate across a broader vary of vehicle operational conditions. The WHTC is a transient test of 1800 s duration, with several motoring segments as shown in graph.

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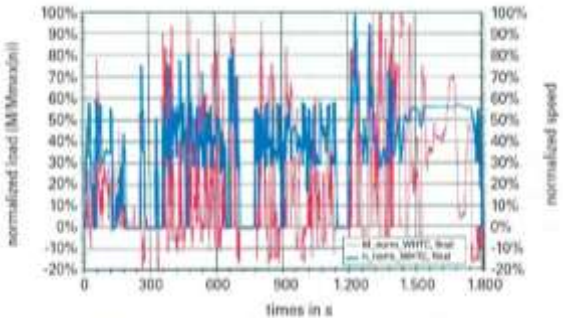

Graph 1 Worldwide Harmonized Transient Cycle

VI. RESULTS

Table 4 Emissions at Constant load and Varying Speed

Speed (rpm)	Brake Power (KW)	Torque (Nm)	BSFC (g/KWhr)	THC (mg/KWH)	CO (mg/KWH)	NOx (mg/KWH)
800	35.93	429	217.08	133	2440	12
1200	54.16	431	221.56	160	3152	37
1600	71.21	425	224.68	156	3540	122
2000	85.24	407	217.03	113	3867	172
2400	95.5	380	225.13	80	4098	252

Table 5 Emissions at Constant speed of 2000rpm and varying load

Load (%)	Brake Power (KW)	Torque (Nm)	BSFC (g/KWhr)	THC (mg/KWH)	CO (mg/KWH)	NOx (mg/KWH)
25	17.59	84	352.47	160	2460	54
50	35.60	170	255.62	141	3226	67
75	63.04	301	223.66	125	3568	129
100	85.24	407	217.03	113	3865	172

VII. DISCUSSION

1. Speed vs Brake Power for Emissions at Constant load and Varying Speed

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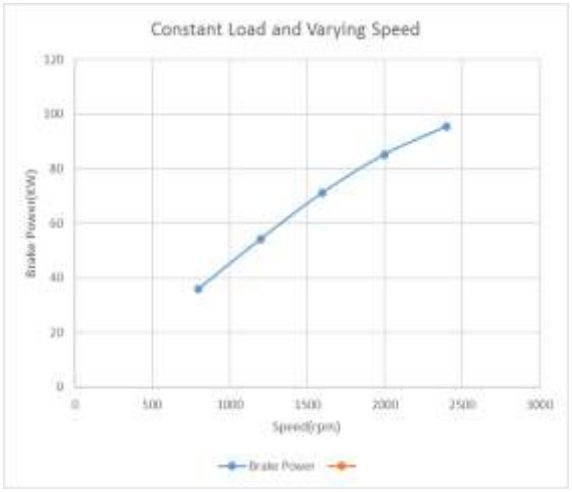
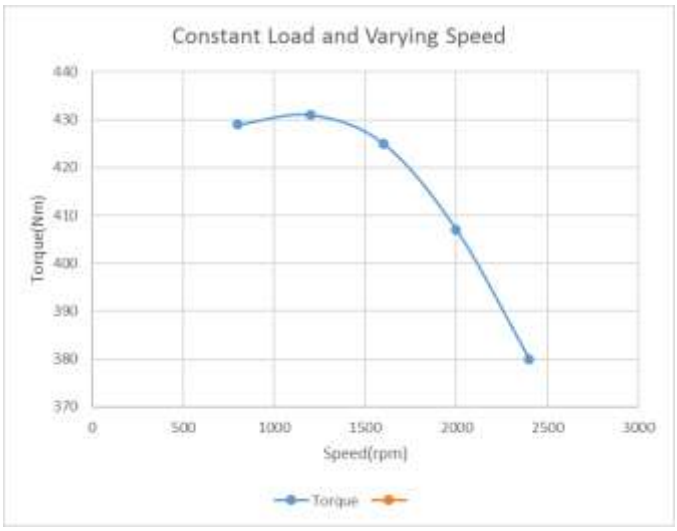


The graph shows how Brake Power increases from 35.93KW to maximum brake power of 95.5KW as speed of engine is increased from 800rpm to 2400rpm. Maximum brake power is achieved at rated engine speed of 2400rpm. It is observed that as speed of engine increases, brake power of engine also increases. Speed vs Torque for Emissions at Constant load and Varying Speed



Graph shows that maximum torque value of 431Nm is obtained at 1200rpm while further increase in engine speed up to 2400rpm reduces the torque output to 380Nm which is minimum torque produced by the engine. It is observed that increase in engine speed reduces torque output of engine.

2. Speed vs BSFC for Emissions at Constant load and Varying Speed

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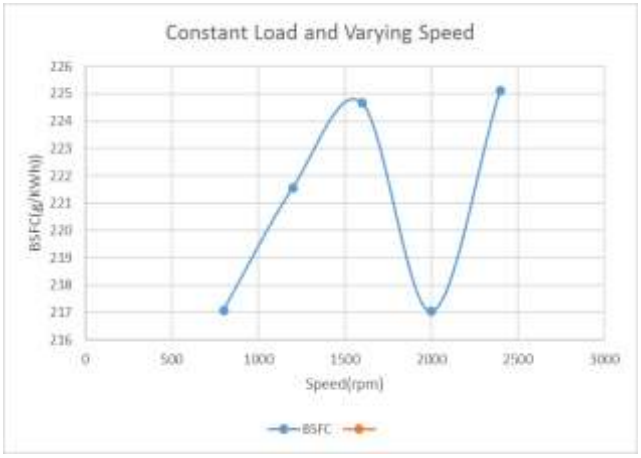
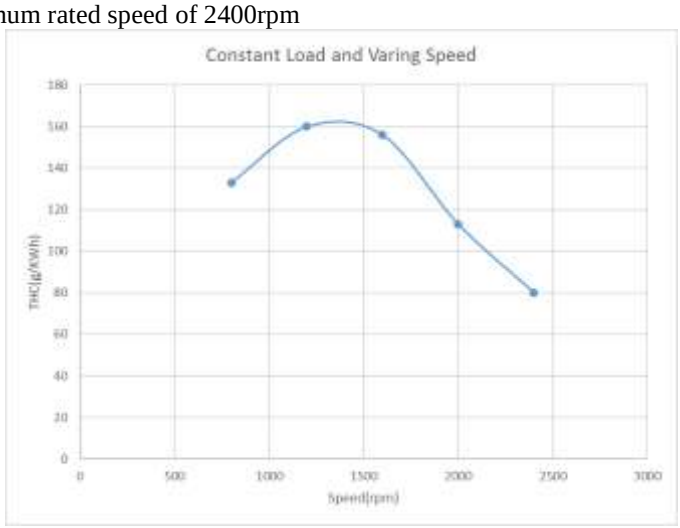


Graph shows how BSFC increases up to 224.68g/KWhr with increase in engine speed till 1600rpms then sudden drops of 217.03 g/KWhr is observed at 2000rpm and then again rises to 225.13g/KWhr at maximum rated speed of 2400rpm

3. Speed vs THC for Emissions at Constant load and Varying Speed



Graph shows how THC emissions increases at 162mg/KWh with increse in speed till 1400rpms and then further emissions are reduces to 80 mg/KWh with increase in engine speed till 2400rpm. As per BS4 norms mean permissible limit for THC was 550 mg/KWh and for BS6 norms mean permissible limit of 160 mg/KWh. Mean emission value for this engine for THC is observed to be 128.4 mg/KWh. Thus BS6 limits for THC emission is achieved.

4. Speed vs CO for Emissions at Constant load and Varying Speed

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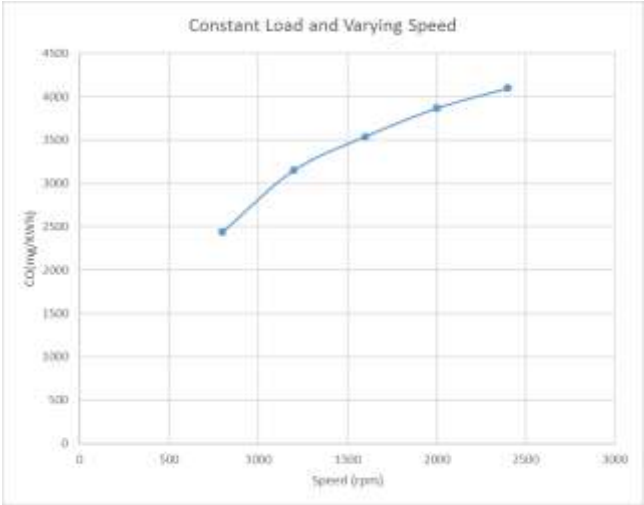
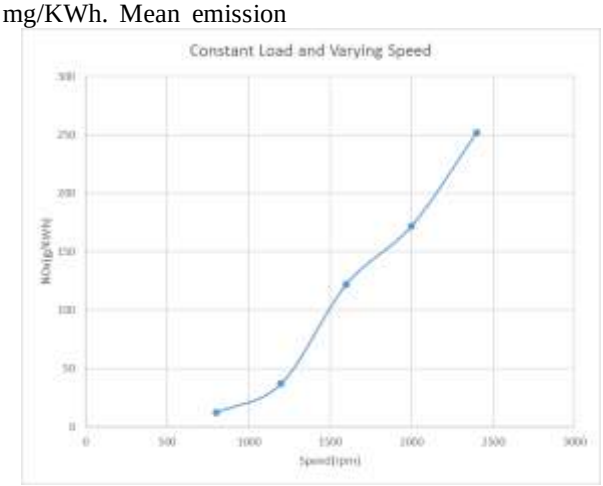


Graph shows that CO emissions increases from 2440 mg/KWh at speed of 800rpm to 4098 mg/KWh at maximum rated speed of 2400rpm. It is observed that increase in speed increases the CO emissions. As per BS4 norms mean permissible limit for CO was 4000 mg/KWh and for BS6 norms mean permissible limit of 4000 mg/KWh. Mean emission value for this engine for CO is observed to be 3419.4 mg/KWh. Thus BS6 limits for CO emission is achieved.

5. Speed vs NOx for Emissions at Constant load and Varying Speed



Graph shows how NOx emissions increases from 10 mg/KWh at 800rpm to maximum emission of 250 mg/KWh at maximum rated engine speed i.e. 2400rpm. Thus it is observed that increase in speed increases the NOx emissions. As per BS4 norms mean permissible limit for NOx 3500mg/KWh and for BS6 norms mean permissible limit of 460 mg/KWh. Mean emission value for this engine for NOx is observed to be 141.2 mg/KWh. Thus BS6 limits for NOx emission is achieved.

6. Speed vs Brake Power for Emissions at Constant speed of 2000rpm and varying load

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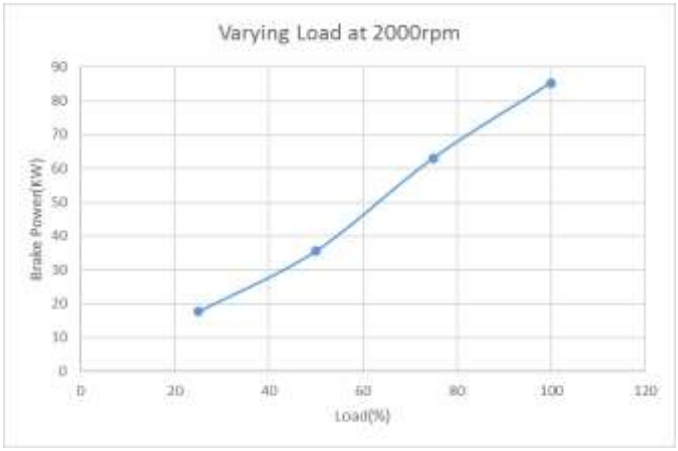
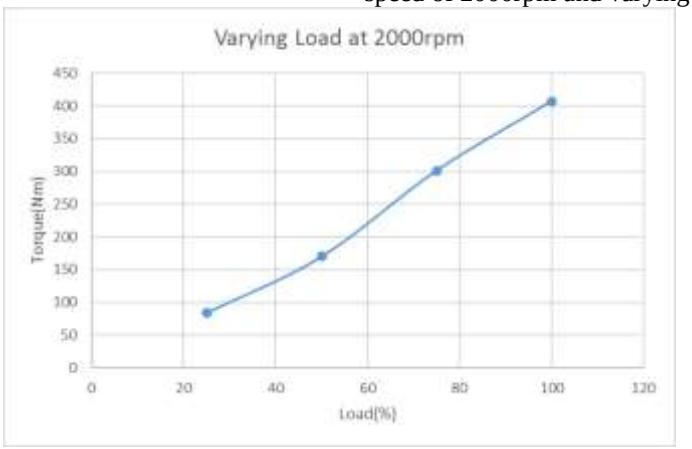


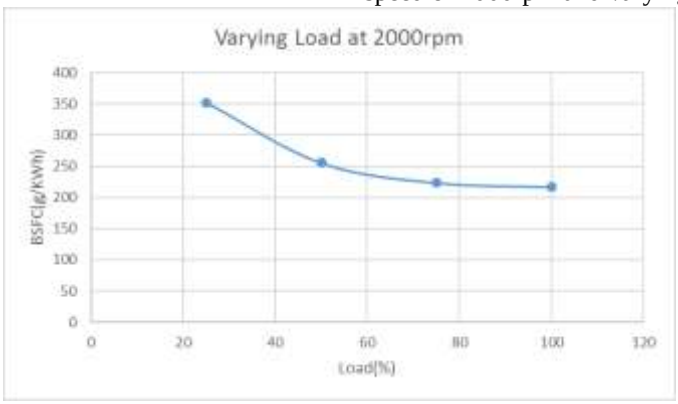
Graph shows that as Brake Power increases from 17.59KW to maximum brake power of 85.24KW as load on engine is increased from 25% to full load. Thus it is observed that at constant speed of 2000rpm, when load on engine is increased brake power of engine also increases.

7. Speed vs Torque for Emissions at Constant speed of 2000rpm and varying load



Graph shows how Torque output of engine increases from 84Nm to 407Nm when load on engine increases. Thus it is observed that as load on engine increases, torque output of engine also increases. Maximum torque output observed at 2000rpm at full load condition is 407Nm.

8. Speed vs BSFC for Emissions at Constant speed of 2000rpm and varying load



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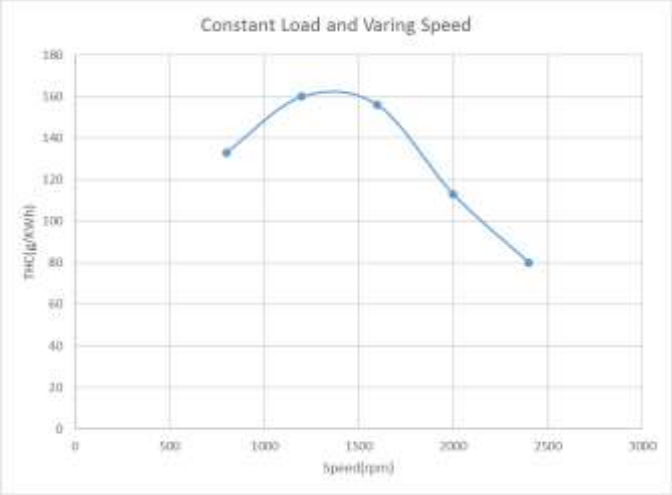
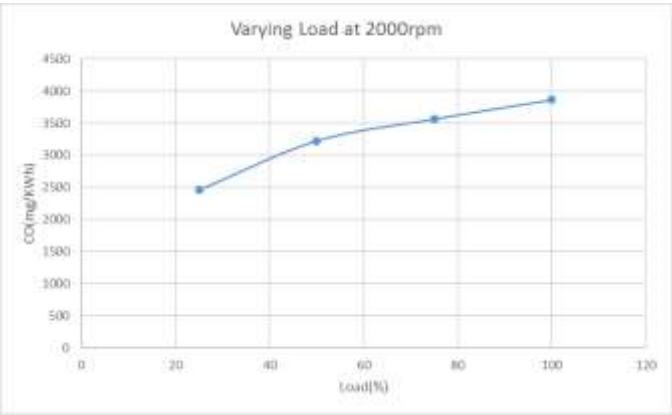
Graph shows how BSFC of engine reduces from 352.47 g/KWhr to 217.03 g/KWhr as load on engine increases from 25% to 100%. It is observed that as load on engine increases, BFSC of engine reduces. Minimum BSFC of 217.03 g/KWhr is observed at 100% load when engine is at constant speed of 2000rpm while maximum BSFC of 352.47 g/KWhr is observed at 25% load when engine is at constant speed of 2000rpm.

9. Speed vs THC for Emissions at Constant speed of 2000rpm and varying load



Graph shows how THC emission of engine reduces from 160 mg/KWH to 113 mg/KWH when load of engine is reduced. It is observed that as load on engine increases, THC emissions reduces. Maximum emission of 160 is observed at 25% load when engine is running at constant speed of 2000rpm while minimum emission of 113 is observed at 100% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for THC was 550 mg/KWh and for BS6 norms mean permissible limit of 160 mg/KWh. Mean emission value for this engine for THC is observed to be 134.75 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for THC emission is achieved.

10. Speed vs CO for Emissions at Constant speed of 2000rpm and varying load



1. Graph shows how CO emission of engine increases from 2460 mg/KWH to 3867 mg/KWH when load of engine is increases. It is observed that as load on engine increases, CO emissions increases. Maximum emission of 3867 mg/KWH is observed at 100% load when engine is running at constant speed of 2000rpm while minimum emission of 2462 mg/KWH is observed at 25% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for CO was 4000 mg/KWh and for BS6 norms mean permissible limit of 4000 mg/KWh. Mean emission value for this engine for 4000 is observed to be 3280.25 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for CO emission is achieved.

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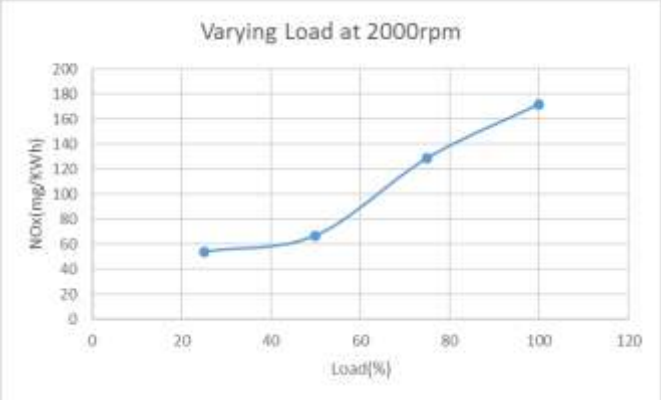
2. Speed vs NOx for Emissions at Constant speed of 2000rpm and varying load



Graph shows how NOx emission of engine increases from 54 mg/KWH to 172 mg/KWH when load of engine is increases. It is observed that as load on engine increases, NOx emissions increases. Maximum emission of 172 is observed at 100% load when engine is running at constant speed of 2000rpm while minimum emission of 54 mg/KWH is observed at 25% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for NOx was 3500 mg/KWh and for BS6 norms mean permissible limit of 460 mg/KWh. Mean emission value for NOx emission is observed to be 105.5 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for NOx emission is achieved.

CONCUSIONS

We have successfully conducted experimentation on 4-cylinder turbo charged engine and engine has successfully meet new Bharat Stage 6 emission norms. Following conclusions has been drawn by experimentation:

1. Brake Power increases from 35.93KW to maximum brake power of 95.5KW as speed of engine is increased from 800rpm to 2400rpm. Maximum brake power is achieved at rated engine speed of 2400rpm. It is observed that as speed of engine increases, brake power of engine also increases.
2. Whereas for constant speed of 200rpm and varying load Brake Power increases from 17.59KW to maximum brake power of 85.24KW as load on engine is increased from 25% to full load. Thus it is observed that at constant speed of 2000rpm, when load on engine is increased brake power of engine also increases.
3. Torque value of 431Nm is obtained at 1200rpm while further increase in engine speed up to 2400rpm reduces the torque output to 380Nm which is minimum torque produced by the engine. It is observed that increase in engine speed reduces torque output of engine.
4. Whereas for constant speed of 200rpm and varying load Torque output of engine increases from 84Nm to 407Nm when load on engine increases. Thus it is observed that as load on engine increases, torque output of engine also increases. Maximum torque output observed at 2000rpm at full load condition is 407Nm.
5. BSFC increases up to 224.68g/KWhr with increase in engine speed till 1600rpms then sudden drops of 217.03 g/KWhr is observed at 2000rpm and then again rises to 225.13g/KWhr at maximum rated speed of 2400rpm.
6. Whereas for constant speed of 200rpm and varying load Graph shows how BSFC of engine reduces from 352.47 g/KWhr to 217.03 g/KWhr as load on engine increases from 25% to 100%. It is observed that as load on engine increases, BFSC of engine reduces. Minimum BSFC of 217.03 g/KWhr is observed at 100% load when engine is at constant speed of 2000rpm while maximum BSFC of 352.47 g/KWhr is observed at 25% load when engine is at constant speed of 2000rpm.
7. THC emissions increases at 162mg/KWh with increse in speed till 1400rpms and then further emissions are reduces to 80 mg/KWh with increase in engine speed till 2400rpm. As per BS4 norms mean permissible limit for THC was 550 mg/KWh and for BS6 norms mean permissible limit of 160 mg/KWh. Mean emission value for this engine for THC is observed to be 128.4 mg/KWh. Thus BS6 limits for THC emission is achieved.
8. Whereas for constant speed of 200rpm and varying load THC emission of engine reduces from 160 mg/KWH to 113 mg/KWH when load of engine is reduced. It is observed that as load on engine increases, THC emissions reduces.

Maximum emission of 160 is observed at 25% load when engine is running at constant speed of 2000rpm while minimum emission of 113 is observed at 100% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for THC was 550 mg/KWh and for BS6 norms mean permissible limit of 160 mg/KWh. Mean emission value for this engine for THC is observed to be 134.75 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for THC emission is achieved.

9. CO emissions increases from 2440 mg/KWh at speed of 800rpm to 4098 mg/KWh at maximum rated speed of 2400rpm. It is observed that increase in speed increases the CO emissions. As per BS4 norms mean permissible limit for CO was 4000 mg/KWh and for BS6 norms mean permissible limit of 4000 mg/KWh. Mean emission value for this engine for CO is observed to be 3419.4 mg/KWh. Thus BS6 limits for CO emission is achieved.
10. Whereas for constant speed of 200rpm and varying load Graph shows how CO emission of engine increases from 2460 mg/KWH to 3867 mg/KWH when load of engine is increases. It is observed that as load on engine increases, CO emissions increases. Maximum emission of 3867 mg/KWH is observed at 100% load when engine is running at constant speed of 2000rpm while minimum emission of 2460 mg/KWH is observed at 25% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for CO was 4000 mg/KWh and for BS6 norms mean permissible limit of 4000 mg/KWh. Mean emission value for this engine for 4000 is observed to be 3280.25 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for CO emission is achieved.
11. NOx emissions increases from 12 mg/KWh at 800rpm to maximum emission of 252 mg/KWh at maximum rated engine speed i.e. 2400rpm. Thus it is observed that increase in speed increases the NOx emissions. As per BS4 norms mean permissible limit for NOx 3500mg/KWh and for BS6 norms mean permissible limit of 460 mg/KWh. Mean emission value for this engine for NOx is observed to be 191 mg/KWh. Thus BS6 limits for NOx emission is achieved.
12. Whereas for constant speed of 200rpm and varying load NOx emission of engine increases from 54 mg/KWH to 172 mg/KWH when load of engine is increases. It is observed that as load on engine increases, NOx emissions increases. Maximum emission of 172 is observed at 100% load when engine is running at constant speed of 2000rpm while minimum emission of 54 mg/KWH is observed at 25% load when engine is running at constant speed of 2000rpm. As per BS4 norms mean permissible limit for NOx was 3500 mg/KWh and for BS6 norms mean permissible limit of 460 mg/KWh. Mean emission value for NOx emission is observed to be 105.5 mg/KWh when engine is running at constant speed of 2000rpm. Thus BS6 limits for NOx emission is achieved.

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