International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 04 | Apr 2022 www.irjet.net p-ISSN: 2395-0072

Compression Ignition Engine Performance Analysis at High Altitude Using Computational Technique

Varnan Gautam[1], Shlok Gupta[1], Ankit Saxena[2]

[1] Student, Department of Mechanical and Automation Engineering, Dr. Akhilesh Das Gupta Institute of Technology & Management, FC-26, Shastri Park, New Delhi – 110053
[2]Assistant Professor, Department of Mechanical Engineering, Dr. Akhilesh Das Gupta Institute of Technology & Management, FC-26, Shastri Park, New Delhi – 110053

---***---

Abstract - *Compression ignition engines are known for its use of superchargers for higher altitudes. With the advent of new techniques in simulation analysis a paradigm shift has been seen in performance analysis of automotive engines. In this work, a turbo Compression ignition engine model is simulated using AVL software. Different fuels are used for performance analysis at sea level & altitudes up to 6000 m. This work also discusses different methods to recover the power loss.*

Key Words: Supercharger, Simulation, Higher altitudes

1. INTRODUCTION

Compression ignition engines don't produce the same power output at high altitude as it gives at sea level due to low atmospheric pressures & low oxygen percentage at high altitude. An engine requires fuel and oxygen in a certain ratio in order for the combustion to take place. Among these two essential requirements, we can only control the amount of fuel injected in a naturally aspirated engine. Amount of Oxygen percentage is dependent upon atmospheric pressure as altitude increases.

Compression Ignition Engine Model has 4 Strokes: in suction stroke the Inlet valve opens and air mixture is sucked into the cylinder through the inlet valve and the piston moves from TDC to BDC. In compression stroke the piston moves from BDC to TDC. In this stroke both the inlet valve and exhaust valves are closed and the air fuel mixture is compressed. In Power stroke power is obtained from the engine by injecting diesel fuel at high pressures. In this process both valves remain closed and due to high compression self-ignition of fuel takes place. In Exhaust Stroke the exhaust valve opens to remove the burned gases from the engine cylinder. Piston moves from BDC to TDC. Burned Gases go from Exhaust Manifold to Turbocharger. The turbocharger's compressor draws-in ambient air and compresses it before it enters into the intake manifold at increased pressure. This results in a greater mass of air entering the cylinders on each intake stroke. The power needed to spin the centrifugal compressor is derived from the kinetic energy of the engine's exhaust gases. An intercooler is also used to cool the air before it enters the engine cylinder.

Studies have been done in order to investigate the effects of high altitude on IC engines. Sivasankaran [1] aimed at increasing the air utilization factor by increasing the charge homogeneity by inducting volatile fuels through the carburettor & showed that it is possible to recover to some extent the power loss of engines by increasing the homogeneity of the charge & Vicente Bermudez [2] have used an Altitude Simulator called HORIBA MEDAS (Mobile Efficient and Dynamic Altitude Simulator). They used this simulator to simulate turbo diesel engines at different altitudes of 150m, 1000m, 2000m, and 3000m. They have used Technologies like EGR (Exhaust Gas Recirculation), VGT (Variable Geometry Turbine), & WasteGate.

It is evident that there is power loss in IC Engines whether it is Gasoline or Diesel Engine when operated at high altitude and it is more evident in case of naturally aspirated engines, however turbocharged & supercharged engines are not affected by this problem at least up to altitude of 3000m,after that it is observed that atmospheric pressure is low due to that there is significant power loss in Turbocharged engines [2] however they are better than naturally aspirated engines at high altitudes. Also it is observed that fuel consumption is increased in both naturally aspirated [11] and forced induction engines [2] when operated at high altitudes. In case of naturally aspirated diesel engines power loss can be compensated to some extent by increasing charge homogeneity & reducing the injection pressure [8] as this will also improve power loss .Engine Emissions also increases as compared to sea level in both naturally aspirated and forced induction engines [3]. It was observed that below 2000 m, the average increasing rates of HC, CO, NOx and smoke are 30%, 35%, 14% and 34% with an increase in altitude of 1000 m, respectively [3]. In the case of Natural gas engines when operating at high altitude using five types of alternative fuels (one at a time) also consisting of different percentages of methane, it was observed that they were operating well & without getting affected by high altitude [4]. In Case of Blends of Biodiesel, ethanol & diesel, when used in turbo diesel engines, brake specific fuel consumption decreases in comparison to diesel engines [12]. but power loss is the same as diesel fuel. With the help of technologies like variable geometry turbine & two stage turbocharging power, it was observed that power loss can be improved significantly.

In this Simulation, a turbo Compression ignition engine model with different fuels is Simulated at sea level & altitudes up to 6000 m. This work also discusses different methods to recover the power loss.

1.1 Motivation

As the atmospheric pressure is inversely proportional to an increase in altitude

$$P_A = \rho_{Hg} g h \qquad \text{eq. 1}$$

when diesel engines are operated at high altitudes they are unable to produce the same Horsepower & Torque that they produce at sea level.

If the engine is stalled when it is at a high altitude then it becomes very difficult to start the engine as the starting torque required to run the engine is not able to be produced by the combustion of diesel fuel.
Increase of Fuel Consumption at High Altitude

2. METHODOLOGY

1) Pre-processing Project Structure:

First a project directory is created, then the client directory where the model is stored. The results directories and files are created automatically.

2) Design the Model:

First the model can be designed by placing the elements in the working area and then connecting them with the pipes. Alternatively, elements can be placed in the required order.

3) General Input Data:

AVL BOOST requires the specification of the general input data prior to the input of any element. Examples like type of simulation Full Cycle or after treatment Simulation, type of Fuel, Initialization etc.

4) Element Input Data:

Data in Individual Elements like Engine, Cylinder, Turbocharger, Air Cooler, Plenums is filled & their properties are selected in order to run the simulation.

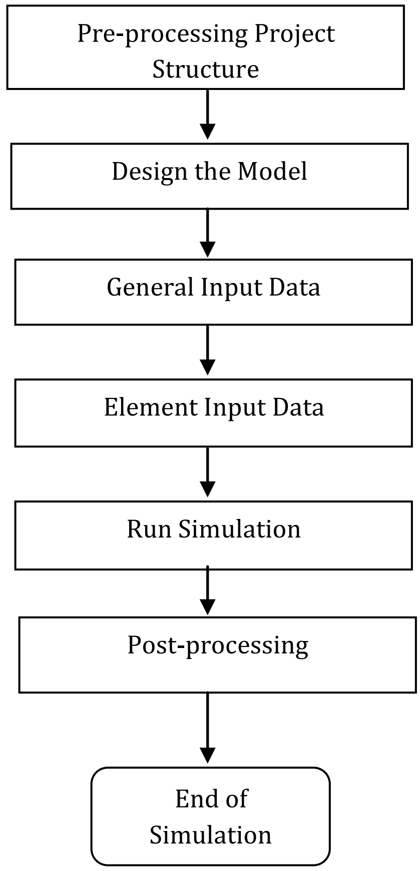
5) Run Simulation:

Simulation is performed after selecting the required cases.

6) Post-processing:

Check for Convergence Warnings & information about simulation run.

Check the results from the transients & traces folder.



3. DESIGN AND ANALYSIS

For Simulation purposes AVL **AVL List GmbH** Software is used Specifically Design of 1D Model of Four Cylinder Turbo Diesel Engine is performed in AVL Boost . AVL BOOST™ simulates a wide variety of engines, 4-stroke or 2-stroke, spark or auto-ignited. Applications range from small capacity engines for motorcycles or industrial purposes up to large engines for marine propulsion.1 D Model of Four Cylinder Turbo Diesel is designed with help of Software Tutorials present in AVL BOOST is used to run simulation of Model is provided in Software Tutorial.

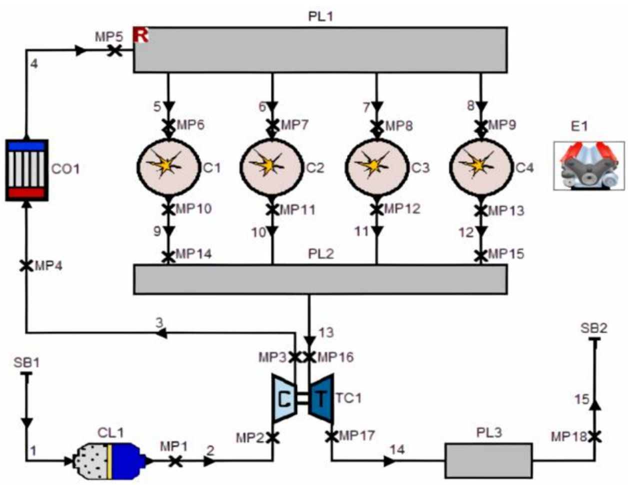


Fig1: Simulation of model

Table1: Components of 1D model

S.No	Name of Part	Quantity	Abbreviation
1	Cylinder	4	C1-C4
2	Turbocharger	1	TC1
3	Air Cooler	1	CO1
4	Plenums	3	PL1-PL3
5	System Boundaries	2	SB1 & SB2
6	Measuring Points	18	MP1-MP18
7	Engine	1	E1

Test 1

The Engine Model is simulated at Sea Level with default stock values. Atmospheric Pressure at both System Boundaries SB1 & SB2 are the system boundary in the above diagram of engine model is kept at 1 Bar. Standard Diesel Fuel is used.

Test 2

The Engine Model is simulated at 4000m Altitude with default setup value. Atmospheric Pressure at both System Boundaries is kept at 0.5 Bar. Standard Diesel Fuel is used.

Test 3

The Engine Model is simulated at 6000 m Altitude with default value. Atmospheric Pressure at both System Boundaries is kept at 0.45 Bar. Standard Diesel Fuel is used.

Test 4

The Engine Model is simulated at Sea Level with default setup. Atmospheric Pressure at both System Boundaries is kept at 1 Bar. This test is performed to see performance gains achieved by using methane fuel in diesel engines. Methane Fuel is used.

Test 5

The Engine Model is simulated at 4000 m Altitude with default value. Atmospheric Pressure at both System Boundaries is kept at 0.5 Bar. Methane Fuel is used.

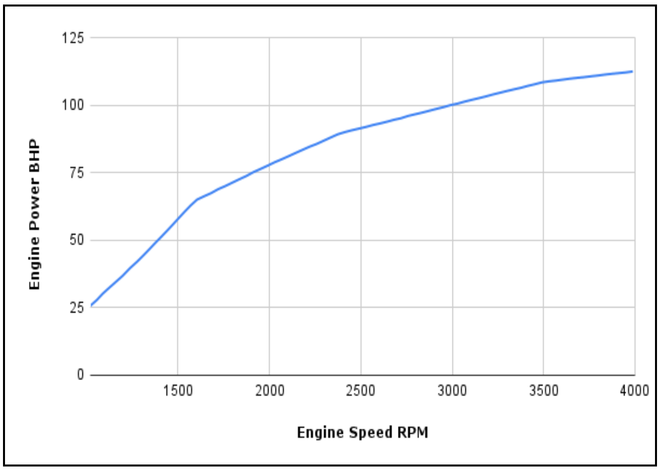
For all Tests Full cycle simulation of the model is carried out in AVL BOOST. Maximum Engine Speed is 4000 RPM.

Table2: Performance of tests with different elevation and fuels

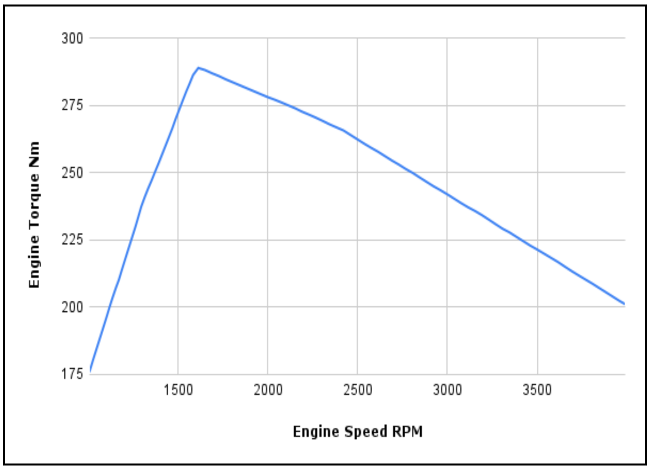
Test No	Elevation Level (m)	Atmospheric pressure (bar)	Fuel used
1	0 m	1 bar	Diesel
2	4000 m	0.5 bar	Diesel
3	6000 m	0.45 bar	Diesel
4	0 m	1 bar	Methane
5	4000 m	0.5 bar	Methane

4. RESULTS & DISCUSSIONS

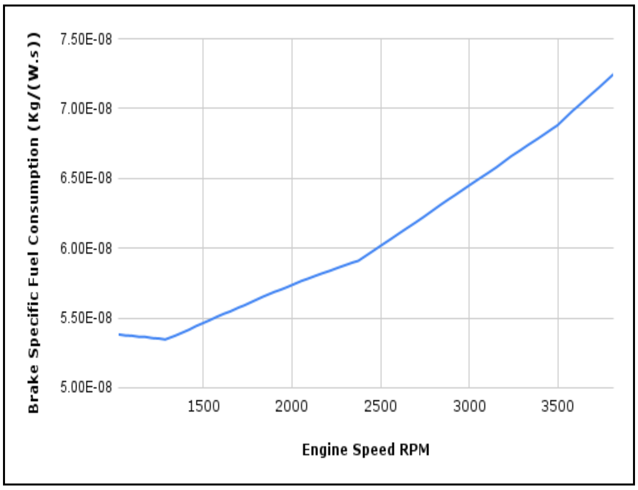
4.1 Result of Test 1: Graph shows that the Engine model produces Maximum Torque of 290 Nm at 1625 RPM & Maximum Power of 115 HP at 4000 RPM. The Brake specific Fuel Consumption is 7.5e-08 Kg/Ws at 4000 RPM. Also Turbocharger produces Boost Pressure of 33.1 Psi at 1000 RPM. Engine Power increases as engine speed increases up to 4000 RPM. Engine Torque decreases after 1625 RPM & reaches a value of 200 NM at 4000 RPM. Brake Specific Fuel consumption is 5.375e-08 Kg/Ws when engine starts & it increases as engine speed increases. Boost Pressure decreases as engine speed increases.



(a)



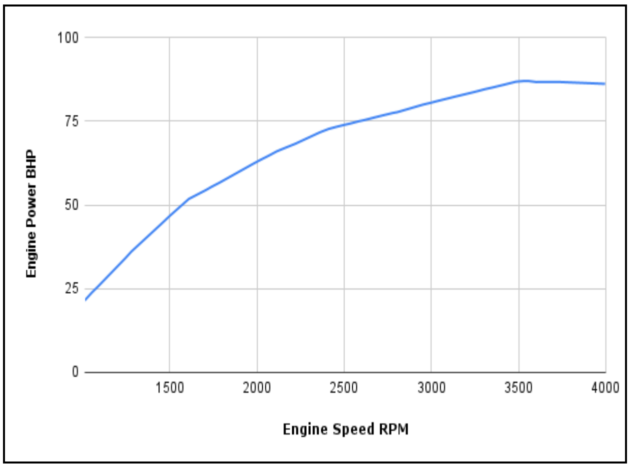
(b)



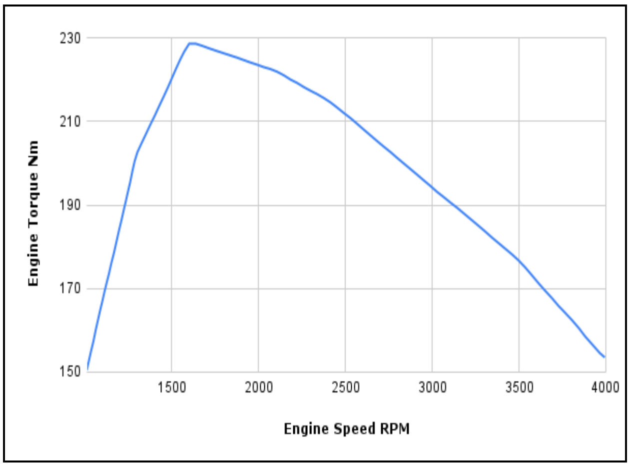
(c)

Fig2: Engine model performance on test 1 (a) Engine power vs Engine speed (b) Engine Torque vs Engine speed (c) BSFC vs Engine speed

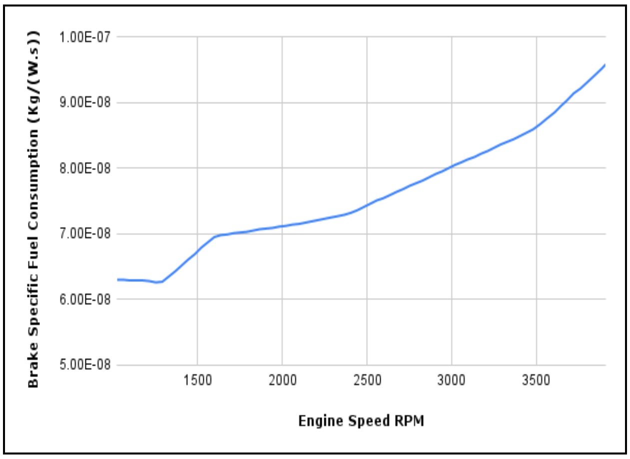
4.2 Result of Test 2: Graph shows that the Engine model produces Maximum Torque of 230 Nm at 1625 RPM & Maximum Power of 85 HP at 4000 RPM which is 20 % & 25 % less respectively than test 1 that is performed at sea level this shows that engine power loss is 25 % at 4000 m of altitude. The Brake specific Fuel Consumption is 1e-07 Kg/Was at 4000 RPM which is 25% more than test 1 this shows engine consumes more fuel at 4000 m. Also Turbocharger produces Boost Pressure of 16.55 Psi at 1000 RPM which is 50 % less than test 1 turbo is not able to make enough boost because of high altitude & low oxygen content. Engine Power increases as engine speed increases up to 4000 RPM. Engine Torque decreases after 1625 RPM & reaches a value of 155 NM at 4000 RPM. Brake Specific Fuel consumption is 6.25e-08 Kg/Ws when engine starts & it increases as engine speed increases. Boost Pressure decreases as engine speed increases.



(a)



(b)

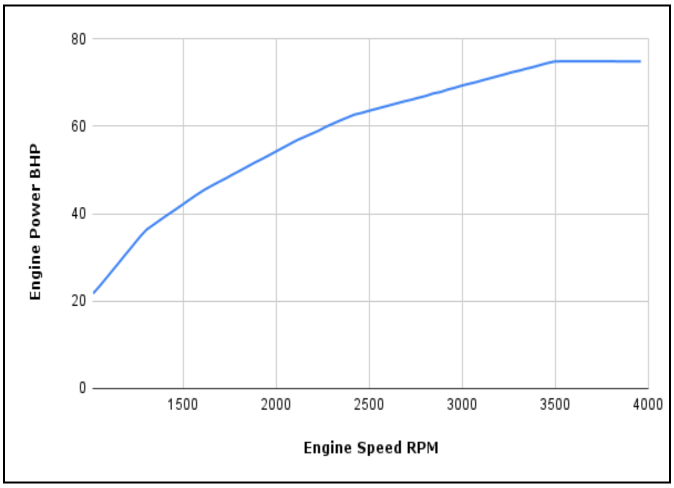


(c)

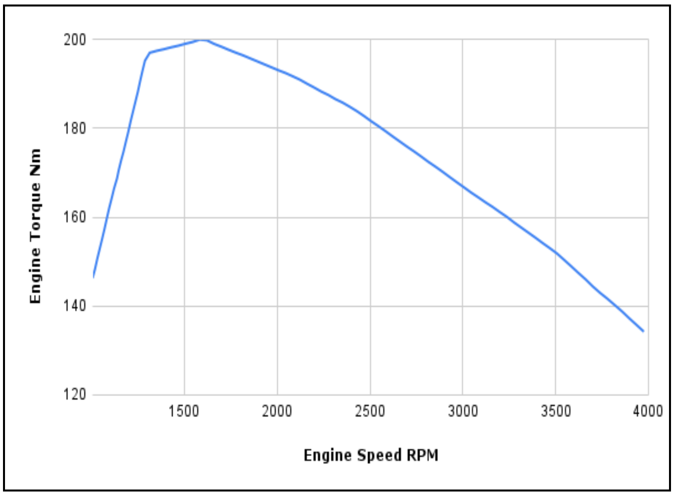
Fig3. Engine model performance on test 2 (a) Engine power vs Engine speed (b) Engine Torque vs Engine speed (c) bsfc vs Engine speed

4.3 Result of Test 3:

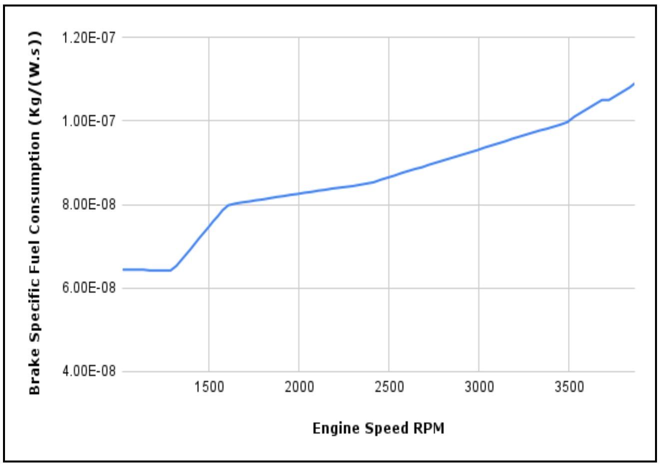
Graph shows that the Engine model produces Maximum Torque of 200 Nm at 1625 RPM & Maximum Power of 75 HP at 4000 RPM which is 31 % & 35 % less respectively than test 1 that is performed at sea level this shows that engine power loss is 35 % at 6000 m of altitude. The Brake specific Fuel Consumption is 1.15e-07 Kg/Ws at 4000 RPM which is 35% more than test 1 this shows engine consumes more fuel at 6000 m. Also Turbocharger produces Boost Pressure of 14.9 Psi at 1000 RPM which is 55 % less than test 1 turbo is not able to make enough boost because of high altitude & low oxygen content. Engine Power increases as engine speed increases up to 4000 RPM. Engine Torque decreases after 1625 RPM & reaches a value of 135 NM at 4000 RPM. Brake Specific Fuel consumption is 6.5e-08 Kg/Ws when engine starts & it increases as engine speed increases. Boost Pressure decreases as engine speed increases.



(a)



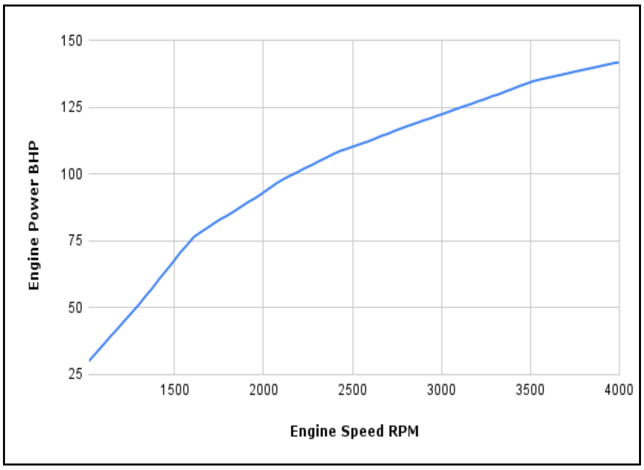
(b)



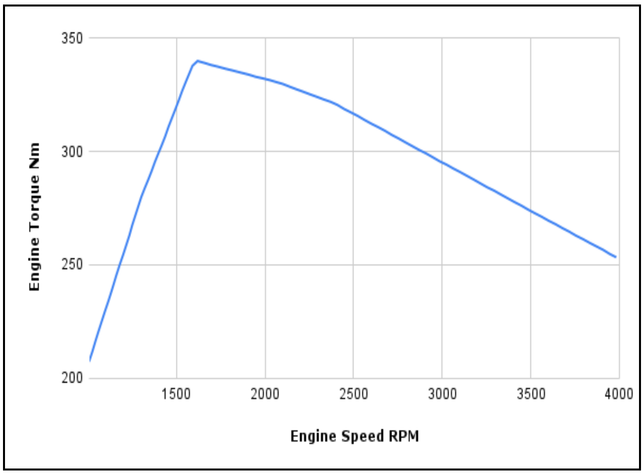
(c)

Fig4. Engine model performance on test 3 (a) Engine power vs Engine speed (b) Engine Torque vs Engine speed (c) bsfc vs Engine speed

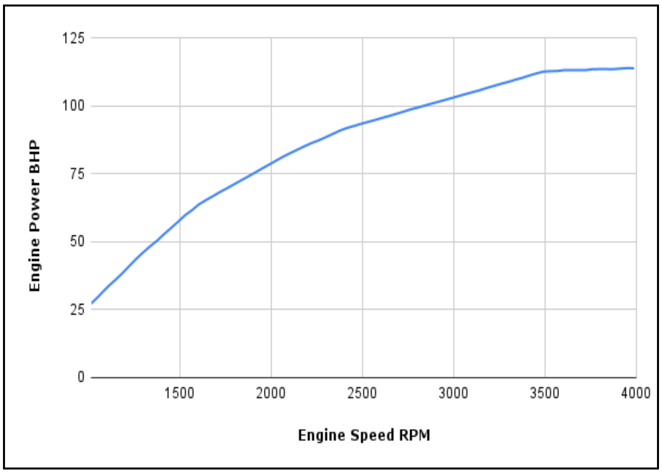
4.4 Result of Test 4: Graph shows that the Engine model produces Maximum Torque of 340 Nm at 1625 RPM & Maximum Power of 140 HP at 4000 RPM which is 20 % more than test 1 because methane fuel is used at sea level for this test. The Brake specific Fuel Consumption is 6e-08 Kg/Ws at 4000 RPM which is 20% less than test 1 this shows with use of methane fuel engine consumes less fuel at sea level. The maximum mechanical efficiency of the engine model is 0.94 at 1625 RPM which is 4% more than stock test 1.Also Turbocharger produces Boost Pressure of 33.1 Psi at 1000 RPM which is same as of test 1 because test is performed at sea level. Engine Power increases as engine speed increases up to 4000 RPM. The Minimum Mechanical Efficiency of Engine Model is .845 at 4000 RPM which is 4% more than test 1.Engine Torque decreases after 1625 RPM & reaches a value of 255 NM at 4000 RPM. Brake Specific Fuel consumption is 4.6e-08 Kg/Ws when engine starts & it increases as engine speed increases. Boost Pressure decreases as engine speed increases.



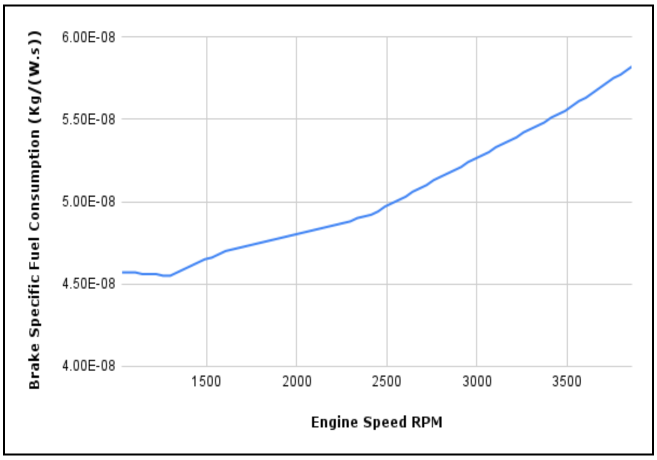
(a)



(b)



(a)

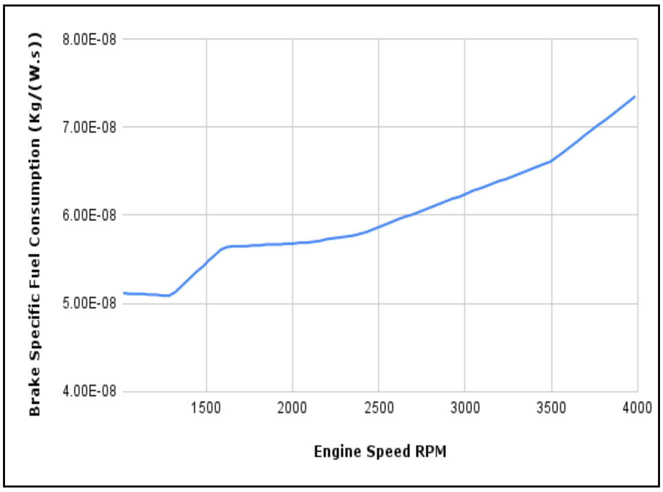


(c)

Fig5. Engine model performance on test 4 (a) Engine power vs Engine speed (b) Engine Torque vs Engine speed (c) bsfc vs Engine speed

4.5 Result of Test 5: Graph shows that the Engine model produces Maximum Torque of 285 Nm at 1625 RPM & Maximum Power of 115 HP at 4000 RPM which is very close to test 1 because methane fuel is used at 4000 m of altitude for this test. The Brake specific Fuel Consumption is 7.375e-08 Kg/Ws at 4000 RPM which is very close to test 1 this shows with use of methane fuel engine consumes same amount of fuel as of sea level for 4000 m altitude. Also Turbocharger produces Boost Pressure of 19.85 Psi at 1000 RPM which is 40 % less than test 1 because the engine is operated at 4000m even though power is the same as sea level. Engine Power increases as engine speed increases up to 4000 RPM. The Minimum Mechanical Efficiency of Engine Model is 0.815 at 4000 RPM which is identical to test 1. Engine Torque decreases after 1625 RPM & reaches a value of 205 Nm at 4000 RPM. Brake Specific Fuel consumption is 5.125e-08 Kg/Ws when engine starts & it increases as engine speed increases. Boost Pressure decreases as engine speed increases.

(b)



(c)

Fig6. Engine model performance on test 5 (a) Engine power vs Engine speed (b) Engine Torque vs Engine speed (c) bsfc vs Engine speed

5. CONCLUSION

Simulation of Turbo Diesel Engine at high altitude of 4000 m & 6000 m is done. Power Loss is 25% at 4000m & 35% at 6000m with standard diesel fuel. With the use of methane at sea level power gain is 20% & when methane is used at altitude of 4000m Power & Torque is close to stock conditions. So this is the solution gathered from the simulation's use of methane at high altitude to compensate for power loss.

REFERENCE

[1] Performance of Diesel Engines at High Altitudes G. A. Sivasankaran and S.K. Jain Indian Institute of Petroleum, DehraDun-248 005 July 1988.

[2] Analysis of the role of altitude on diesel engine performance and emissions using an atmosphere simulator. (International Journal of Engine Research) Vicente Bermu´dez, Jose´ Ramo´n Serrano, Pedro Piqueras, Javier Go´mez and Stefan Bender 2017, Vol. 18(1-2) 105–117.

[3] Emission characteristics of a heavy-duty diesel engine at simulated high altitudes (Elsevier Science Direct) Chao He,Yunshan Ge, Chaochen Ma, Jianwei Tan, Zhihua Liu, Chu Wang, Linxiao Yu, Yan Ding , 31 May 2011.

[4] Performance of Alternative fuels at high altitudes (Paul S. Sarbanes Transit in Parks Technical Assistance Center) April 2012.

[5] Effects of altitude and fuel oxygen content on the performance of a high Pressure common rail diesel engine (Elsevier Science Direct).Shaohua Liu, Lizhong Shen, Yuhua Bi, Jilin Lei 2013.

[6] Simulation of High Altitude Effects on Heavy-Duty Diesel Emissions SAE Technical Paper Series,David M. Human, Terry L. Ullman, Thomas M. Baines, April 3-5, 1990.

[7] Effects of Altitude and Temperature on the Performance And Efficiency of Turbocharged Direct Injection Gasoline Engine (Journal of Applied Fluid Mechanics) S. Motahari and I. Chitsaz, Vol. 12, No. 6, pp. 1825-1836, 2019.

[8] High-altitude Matching Characteristic of Regulated Two-Stage Turbocharger with Diesel Engine (Journal of Engineering for Gas Turbines and Power ASME) Ruilin Liu, Zhongjie Zhang, Surong Dong, Guangmeng Zhou, March 17, 2017.

[9] Performance of a single-cylinder diesel engine using oxygen-enriched intake air at simulated high-altitude conditions (Elsevier Science Direct) Peter L. Perez, Andre L. Boehman 20 August 2009.

[10] Effects of altitude on the thermal efficiency of a heavy-duty diesel
Engine (Elsevier Science Direct) Xin Wang, Yunshan Ge, Linxiao Yu, Xiangyu Feng, 19 July 2013.

[11] Performance Of Naturally Aspirating IC Engines Operating At High Altitude, Dieter Gerner, Journal of EAEA, Vol. 10, 1993.

[12] Performance, combustion timing and emissions from a light duty vehicle at different altitudes fueled with animal fat biodiesel, GTL and diesel fuels Ángel Ramos Elsevier Science Direct August 2016.