Performance analysis of variable geometry turbocharged CI engine

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Abstract. Taking into consideration the rapid rate at which conventional sources of energy are depleting, the need of the hour is to come up with novel ideas that can be implemented to improve the efficiency with which engines were running on conventional resources such as gasoline and diesel. Two main factors that have been taking into consideration towards coming up with a novel solution for sustainability are power and fuel efficiency, To because no viable alternative has invented the conventional resources of energy, it is of Cardinal importance that we extract as much power as possible from as little fuel as we Can. This project primarily focuses on these two characteristics and solutions to improve them. For a long time now turbochargers have been known to provide an additional boost of power for internal combustion engines. The disadvantage being the turbo lag that exists during their implementation at low speeds. With a novel technique implemented in this project, it is possible to achieve the desired boost over a wide range of speeds. With the excess air available for combustion as a result of turbo charging, it is also feasible to ensure a cleaner and greener combustion with reduced emissions, thereby ticking all the boxes in our fight towards sustainability.

Keywords. Turbo charger, HC emissions, NO_X, Engine speed

1. Introduction

Ashish O Jain et al [1] in their Investigation on the effects of turbocharger and intercoolers on CI Engine performance & Exhaust emissions using wind power analyzed the effect of turbocharging on the performance and emission characteristics of a CI engine. They observed an improvement in the Brake Power, Loading capacity and volumetric efficiency. Ganapathi. R et al [2] in their study of The Effect of Turbocharging on Volumetric efficiency in Low Heat Rejection C.I. Engine fuelled with Jatropha for Improved Performance compared the volumetric efficiency improvement for implementation of a turbocharger on a naturally aspirated CI engine and observed a substantial increase in the volumetric efficiency for both biodiesel and normal diesel operation. Khaled M. et al [3] in their Study of EGR and TurbochargerCombinations and Their Influence on Diesel Engine's Efficiency and Emissions used a combination of EGR and turbochargers to analyze the impact on emissions. It is observed that this setup provided results that were similar to other publications, but the usage of EGR enabled them to bring down the NO_x emissions substantially as well.S.Saulnieret al [4] Computational study of diesel engine downsizing using two-stage turbocharging focussed primarily on developing a computational model for studying the impact of turbochargers on performance characteristics. Niemi, S., et al [5] study of the Effect of Waste-Gate Turbocharging on the Exhaust

Particulate Matter of an Off-Road Diesel Arnold.S et al [6] studies utilized a system of electronic assistance for turbocharged systems which can take over from the turbocharger during the turbo lag period. The auxiliary system used during the turbo lag period was an electric air blower.

2. Experimental Analysis

Variable Geometry Turbocharger Experiment having analyzed the major issues in the literature survey, it concluded that the deviation in performance characteristics in almost all cases caused as a result of turbo lag. Building upon this conclusion, it was decided that a system using a variable geometry turbocharger adaptation on an engine is analyzed and compared with the values of the driving force without a VGT. To investigate these effects, a more in-depth analysis of other parameters is required. This necessity demands a bigger better setup that can be used to capture a wider variety and range of data to analyze.

2.1 System Design

For conducting experimental analysis using a VGT, the most critical areas of concern that need to include:

- Finding a suitable turbocharger and engine to work with
- Preparing the actuation mechanism
- Preparation of mechanical supports for mounting
- Suitable Intercooler provision
- Making arrangements for data capturing
- Making arrangements for obtaining emission data

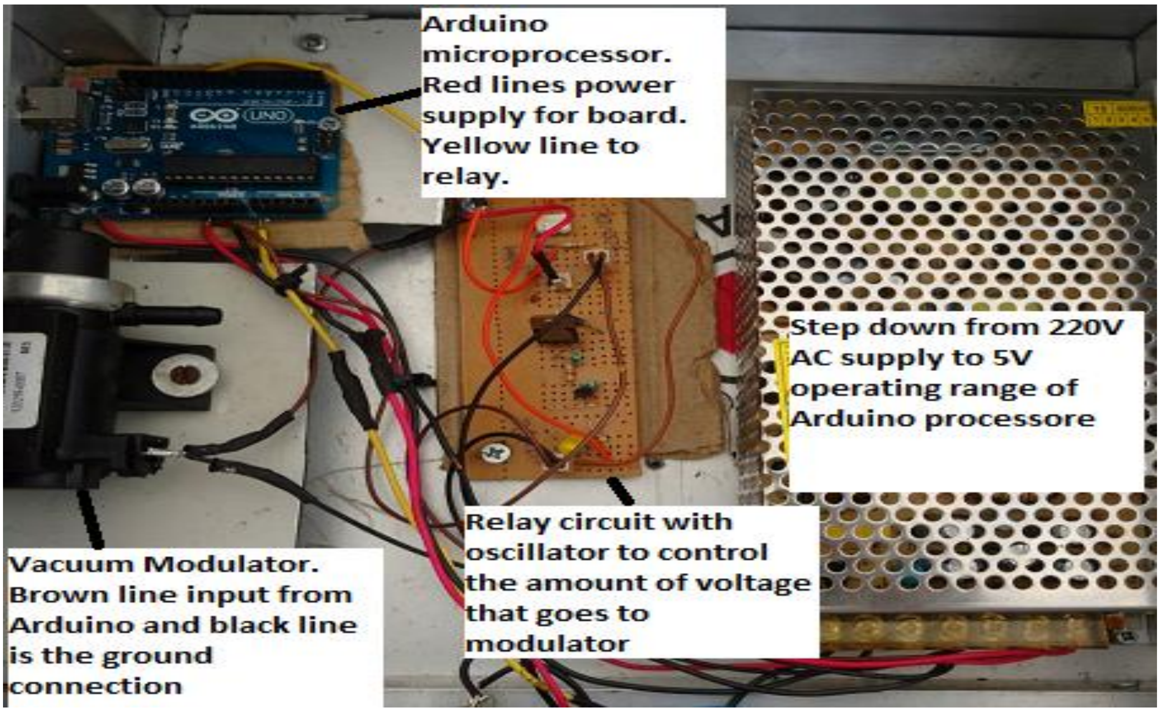

Figure 1. Electronic Connections

Once the engine for application had been zeroed down, the next step is to use the engine's data for designing the actuation mechanism. The engine data provided information about the speed range of the engine. This data was used to arrive at a logic for the actuation mechanism. As discussed earlier the actuation mechanism comprises of the Arduino processor, AC-DC converter, relay circuit, vacuum modulator, vacuum lines and linear actuator of the VGT. The entire range of speeds was divided into ten parts to simplify the logic. The program was developed to cater these ten fields with different digital output signals from the Arduino that would, in turn, send corresponding oscillator frequencies for the movement of the plunger. Also, a potentiometer is made available to make sure that the if the same system has to implement in a similar capacity engine with different speed range, the speed step variations of the ten divisions can be compensated by manually setting the potentiometer. The potentiometer range is divided into ten steps to replicate the ten-speed steps of the engine. Instead of the tachometer providing an analog input to the Arduino, the potentiometer's change in resistance is used as an input to the Arduino. The rest of the steps involved in the actuation process is the same as that for a system with a tachometer input.The figure shows the various components of the electronic actuation system connected.Once the logic and connections have been made, the next step is to come up with a source for supplying vacuum to control the system. Taking into consideration the fact that this project finds its application in automobiles, the source of vacuum must be designed such that the requirement for radical changes in the design of engines is not there. Also, it should be something that can obtain from existing automotive technology. After going through the various options at hand, it was decided that the source of vacuum supply would be an alternator with a vacuum pump. Vacuum pump type alternators are available in the market and hence do not require a radical development in technology for adaptation. The principle of operation of the vacuum pump type alternator is that it uses a pulley system to drive a vacuum pump via a dynamo. Since the engine that used for testing already has a different type of alternator, an electric motor was used to drive the alternator through a coupling.

The specifications of the engine motor and alternator setup are listed below

Table 1. Alternator and Motor Specifications

Parameter	Detail
Alternator Type	Vacuum Pump Type
Alternator Make and Model	TATA Indigo Manza
Alternator Power Supply	Drive From Motor
Motor Speed	2880 rpm
Motor Power Supply	220V AC supply
Motor Capacity	0.5 hp
Motor Speed	2880 rpm (Constant Speed)
Coupling Type	Internal Gear Polymer Coupling

The choice of the alternator was a result of analyzing various commercial options available in the market and matching it with the requirements of the power delivery from test engine. It decided that the alternator from a TATA Indigo Manza will be used for application in this project. The decision influenced by the fact that the model mentioned above uses. A vacuum pump type alternator and the engine capacity of the same was similar to that of the test engine. Next issue was the choice of motor to drive the alternator. It decided that the motor from the monoblock pump used since it operated at 2880rpm which is more or less the speed at which IC engines run.

The vacuum lines connect the vacuum out port of the alternator to space in a port of the vacuum modulator and similarly the vacuum out port of the vacuum modulator is attached to the vacuum port provided on the diaphragm housing, 6mm inner diameter rubber hoses used for this purpose. Once all the connections made, the system was checked by using the potentiometer. All nine levels of the

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potentiometer's limits were operated and checked if the linear actuator responded for all levels of potentiometer change.

Once the actuation system was taken care of, the next step was to make arrangements for adaptation on the existing naturally aspirated engine. Crucial factors need to take into consideration include making sure that the exhaust port on the turbocharger housing is in line with the current exhaust pipe that carries the exhaust gasses out of the laboratory through the muffler. The mechanical joints that required for adaptation of the turbocharger started with a triangular flange with provisions for 3 M30 bolts at the edges of the triangles. The angular flange had a 40mm diameter hole in it upon which a 40mm pipe with internal thread facing away from the flange welded. The inner thread on this tube was made to match with the threads on the pipe coming out of the engine exhaust manifold. Before the thread fastened on each other, Teflon tapes were used ensure that the system was properly sealed.

Another triangular flange made to match the one connected to the exhaust manifold prepared with the same provision for pipe welding. An L-joint bending perpendicularly downwards was welded onto this flange. Both the flanges were fastened together using M30 bolts and matching nuts. In between the flanges, a rubber gasket was placed to make sure there was no loss in exhaust gas pressure going to the turbocharger as a consequence of leakage. Before the L-joint, a 10mm inner diameter nipple with the internal thread was provided for thermocouple mounting. The lower end of the pipe facing downwards welded with another similar flange and three holes for M30 bolts which placed at the edges. These three bolts fastened onto the threaded holes provided in the turbocharger's turbine housing at the turbine inlet.

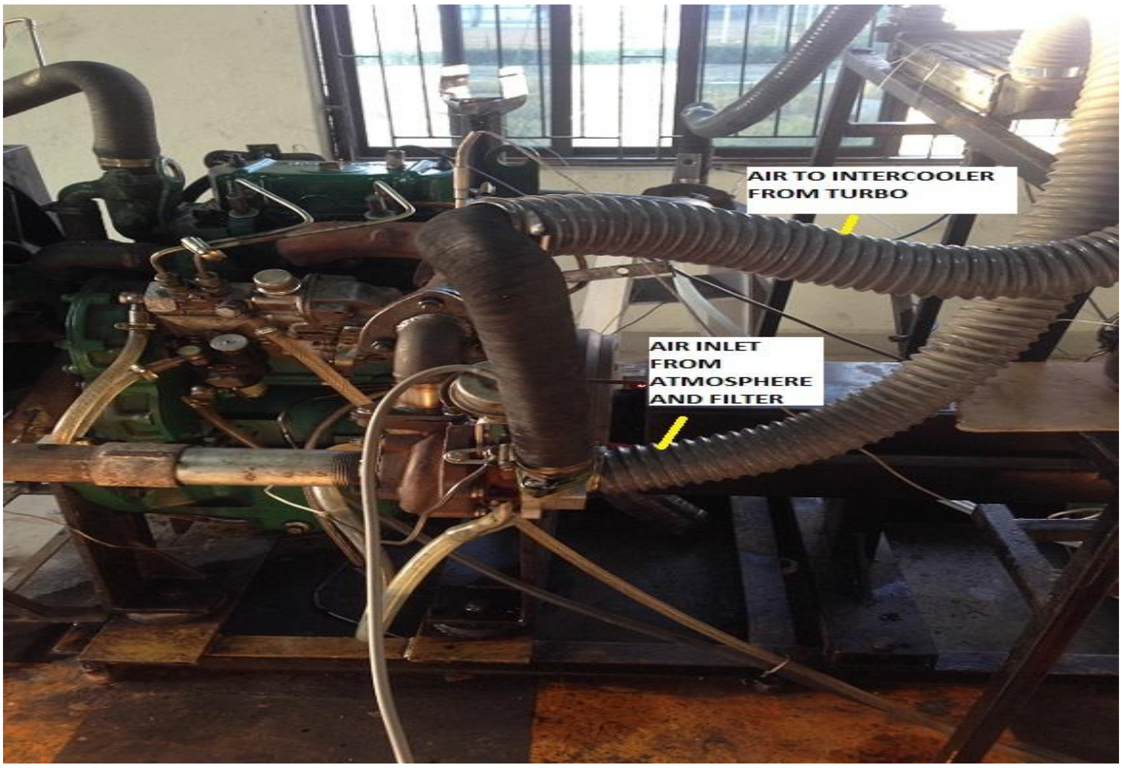

Figure 2. Complete Turbocharger Mounting on Engine

Once the turbine inlet has been taken care of, the next step involves making provisions for the exhaust gasses to move out of the turbine housing to the muffler and into the open atmosphere. This was achieved by using similar triangular flanges and M30 bolts which fastened into the turbine housing with the flange in position. The next and final step on the turbine side of the turbocharger's mounting is to attach the threaded pipe coming out of the turbine housing onto the pipe going into the muffler. All the flanges and pipes used for the turbine side of the turbocharger are made of cast iron to withstand the high temperatures and pressures associated with exhaust gasses and to resist thermal expansion due to heat as much as possible. The compressor side of the turbocharger is relatively easier to mount since flexible rubber hoses can use for the relatively cooler air that goes into the engine for combustion.Before the atmospheric air enters the turbocharger, it is filtered by an air filter. After passing through the turbocharger, the air is then sent to the engine through an intercooler. Intercoolers help in increasing the effectiveness with which turbochargers operate by cooling the compressed air to increase further the density of air going into the combustion chamber. For this application, an air type intercooler was used which cooled the air going into the engine by using fins in contact with the atmosphere. Thermocouples were fixed on the pipe that carried air into and out of the intercooler.

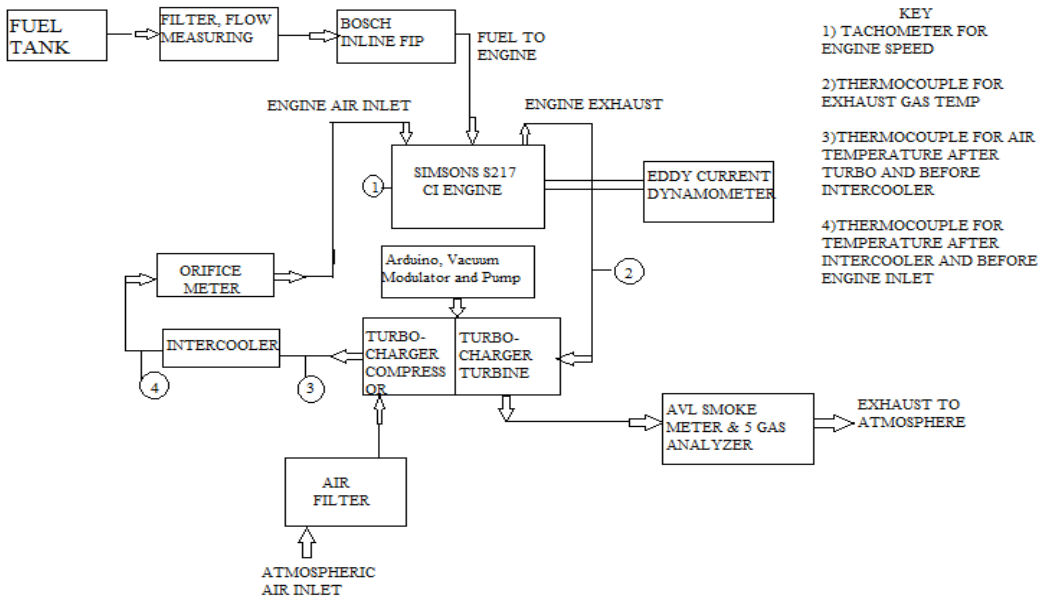

Figure 3. Experimental schematic diagram

Table 2. Test Engine Specifications

Parameter	Detail
Model	Simpsons S217
Configuration	Vertical In-line
Number of Cylinders	2
Number of Strokes	4
Capacity	21kW at 2000rpm
Cubic Capacity	1670cc
Bore	91.44mm
Stroke	127mm
Starting	12V Electrical Motor
Combustion System	Direct Injection Diesel

Cooling System	Water Cooled
Fuel Pump	Bosch Inline FIP
Aspiration	Natural

3. Experimental Procedure

After making all the necessary arrangements for conducting the experiments made, the next step is to establish an innovative system that can help obtain results and analyze all possible avenues in which the variable geometry turbocharger affects the performance and emissions of the engine. Before starting the experiment test run for 5 minutes at different speeds. In the test runs, it was observed that the vibrations in the engine gradually started increasing in intensity after it reached speeds of 1700 rpm. For safety reasons, the engine was operated at speeds less than 1600 rpm. Controlling the speed was achieved by using a threaded rod attached to the throttle of the FIP. On the other end of the rod, a nut was fastened and placed near a support bracket. , the rod is pulled to increase the speed of the engine. Which in turn pulls the throttle arm of the FIP. The nut is fastened to the bracket so that the rod and consequently the throttle arm held in its position to fix the rated speed.

The experiment involved taking readings at three speeds and five loads for each speed. Since the engine cannot load at idling speeds, the speeds were decided upon were 1000, 1200 and 1400rpm. For each speed, the engine was set to a speed slightly higher than the rated speed determined, and the engine was gradually loaded to bring it down to the target speed. For example, to take readings at 1000 rpm, the engine first operated at 1150 rpm and load is applied gradually to bring it down to 1000 rpm. The pressure that is applied when the engine reads 1000rpm is considered to be 100% capacity for that speed. Once the value for this weight obtained, the 75%, 50%, 25% load values calculated. The same procedure repeated for 75%, 50%, 25% and no load condition and similarly, the same process is repeated for a setup without the VGT.

4. Results and Discussion

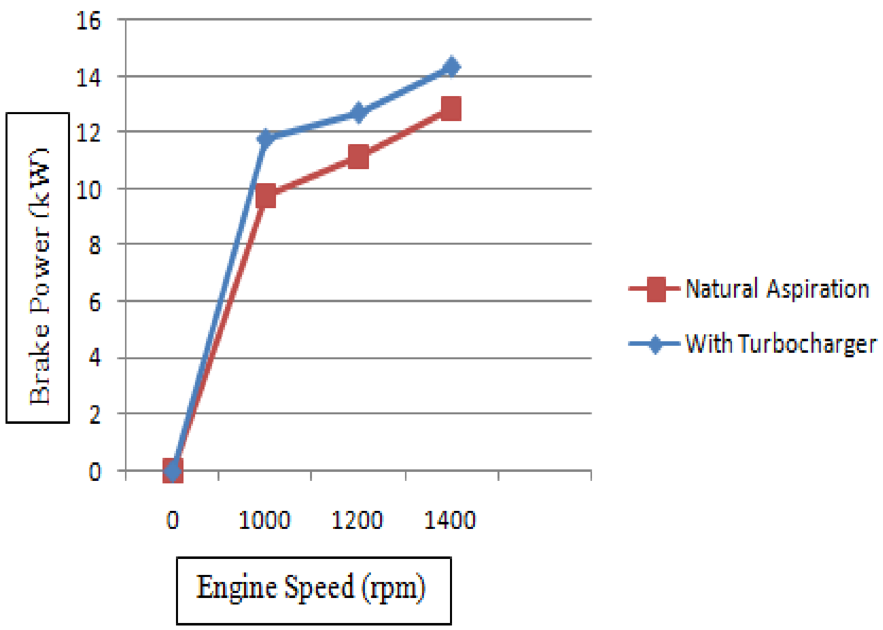

Figure 4. BP vs Engine speed for Max load

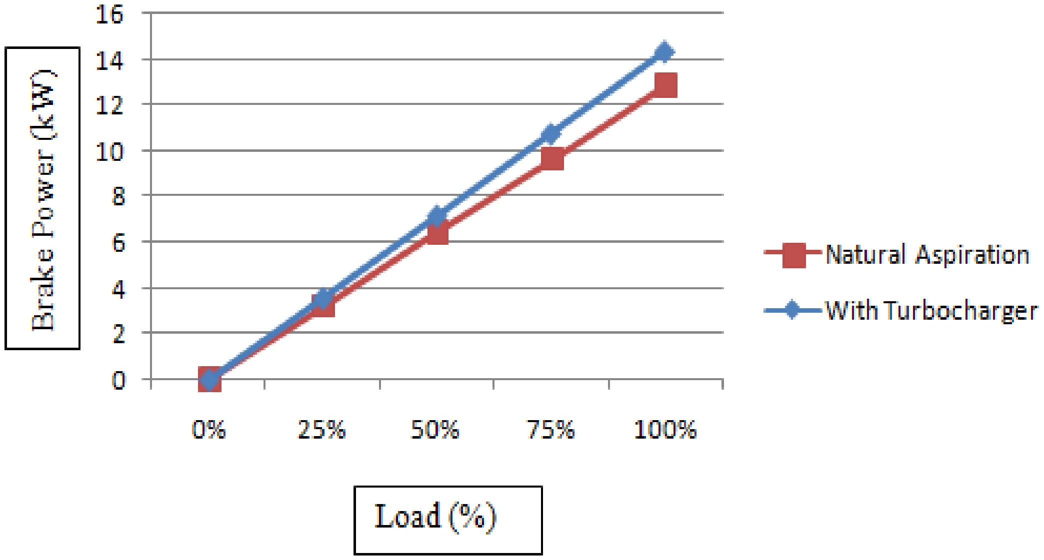

Figure 5. BP vs. Load at 1400 RPM

From the above figures, it is clear that the BP has improved significantly for all speeds right from 1000rpm without turbo-lag. Also, no deviations from the expected results were observed when the brake power compared with a load for max speed. The graph shows that the VGT has a positive effect on power delivery over a wide range of speeds.

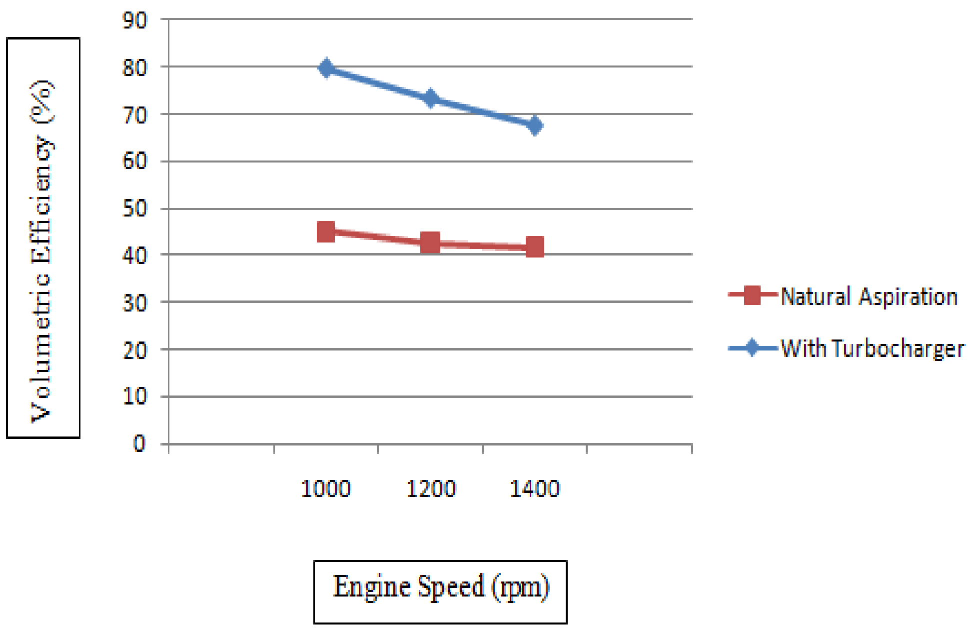

Figure 6. Volumetric Efficiency vs. Engine Speed

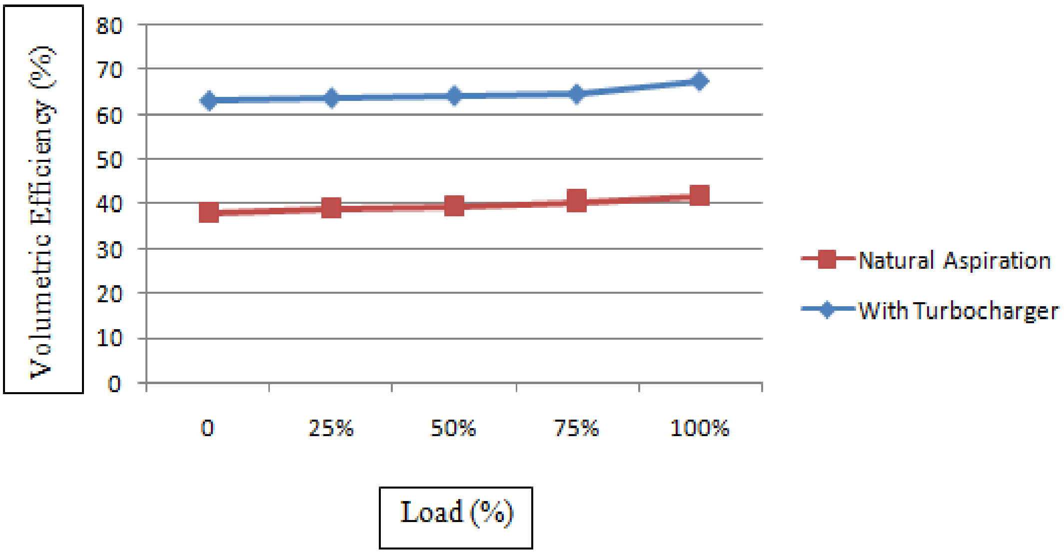

Figure 7. Volumetric Efficiency vs. Load

Again, when volumetric efficiency was taken as a basis for comparison with a naturally aspirated system and turbocharger, compressing air through the compressor has resulted in an increase in mass flow rate air entering the combustion chamber leading to an improved volumetric efficiency over all three speeds. The volumetric efficiency readings too, haven't shown any signs of turbo-lag. Hence VGT adaptation has also helped increase the volumetric efficiency of the naturally aspirated engine.

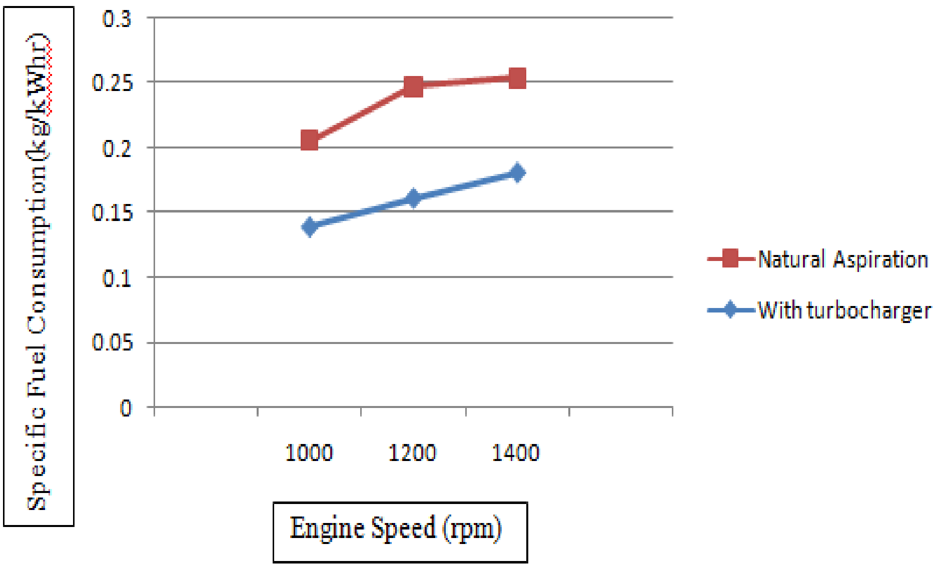

Figure 8. SFC vs. Engine Speed at Max Load

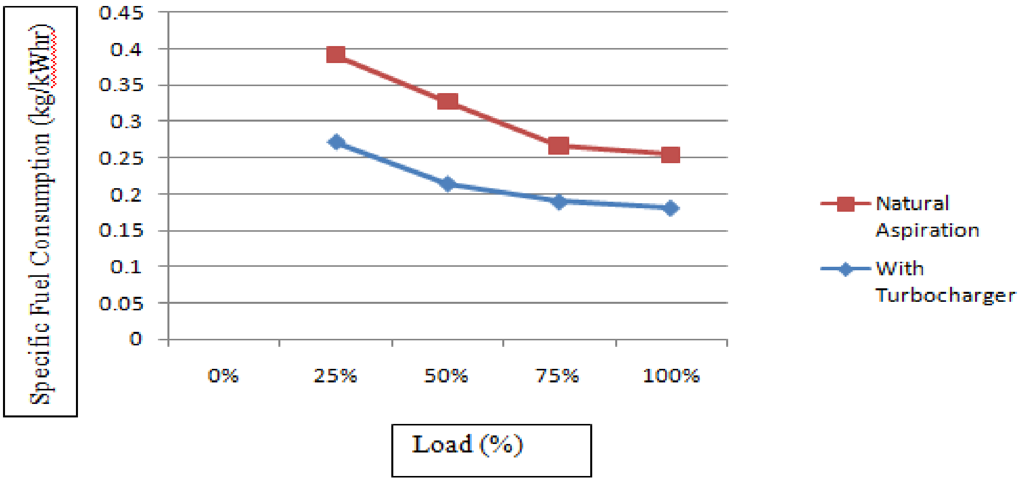

Figure 9. SFC vs. Load at Max Speed

The above graphs suggest that the Specific fuel consumption for a given speed at maximum load have reduced significantly suggesting an improvement in fuel efficiency of the turbocharged system over the naturally aspirated system for a given speed. Similarly, the trends for the comparison at the constant speed for different load values have also suggested that the adaptation of the VGT improves the fuel efficiency of the engine. The graphs also indicate that the improvement in parameters has observed for all speeds showing the lack of any turbo-lag.

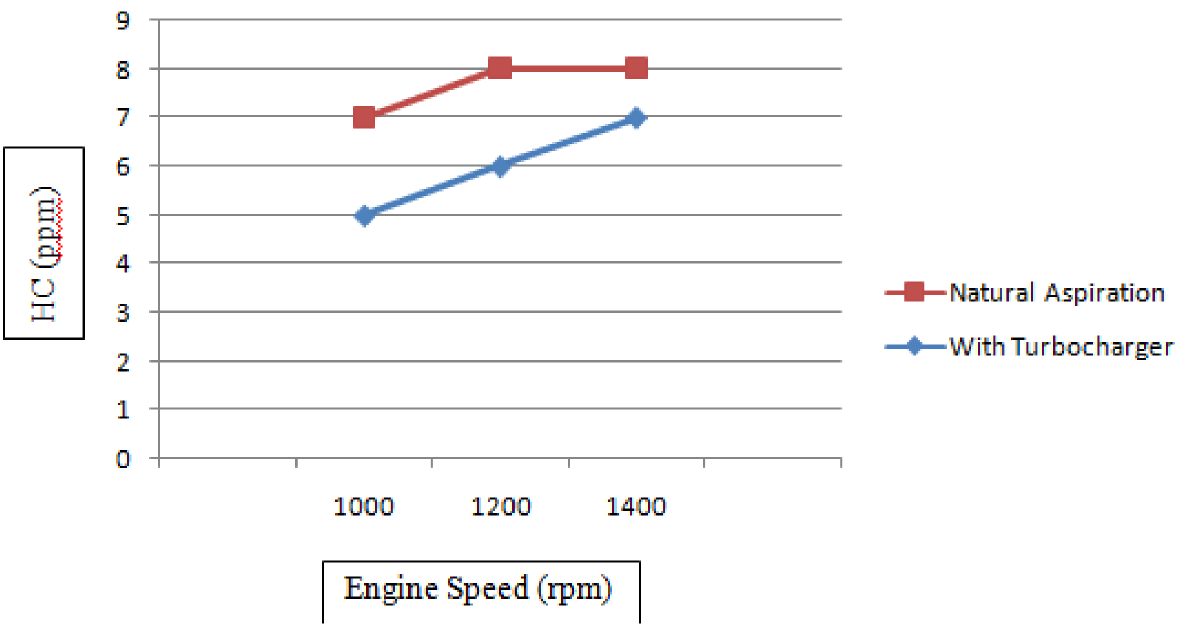

Figure 10. HC emissions vs. Engine Speed at Max Load

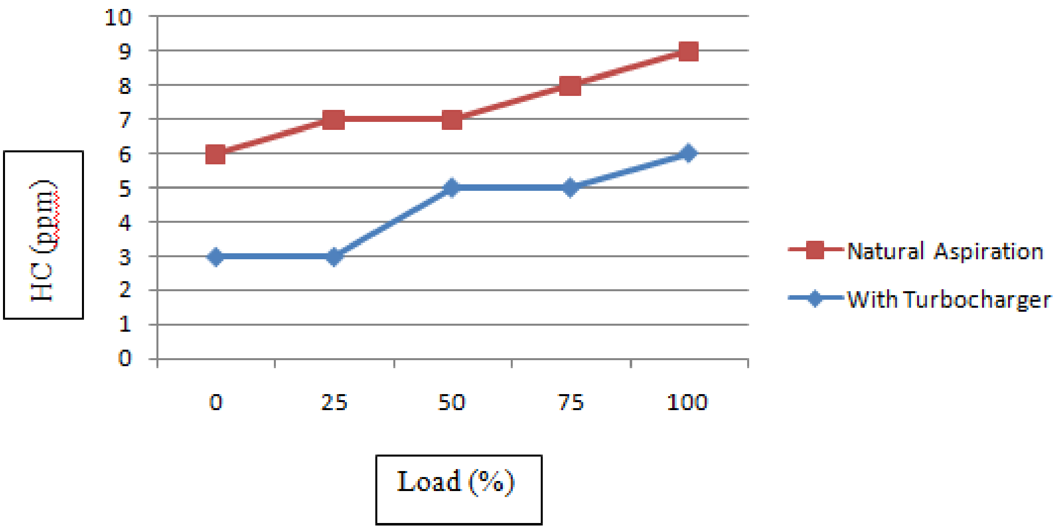

Figure 11. HC emissions vs. Load at Max Speed

From the graphs, it can observe that the HC emissions for the VGT system are well below that of the naturally aspirated engine. It shows attributed to better combustion of the fuel in the presence of excess air when the VGT used. For the same speed, the amount of air that goes into the combustion chamber for the naturally aspirated system is less, and hence combustion is not complete. Since the primary cause of HC emissions in incomplete combustion, the HC emissions for the naturally aspirated engine was higher than that of the turbocharged system. Again, there was no sign of turbo-lag.

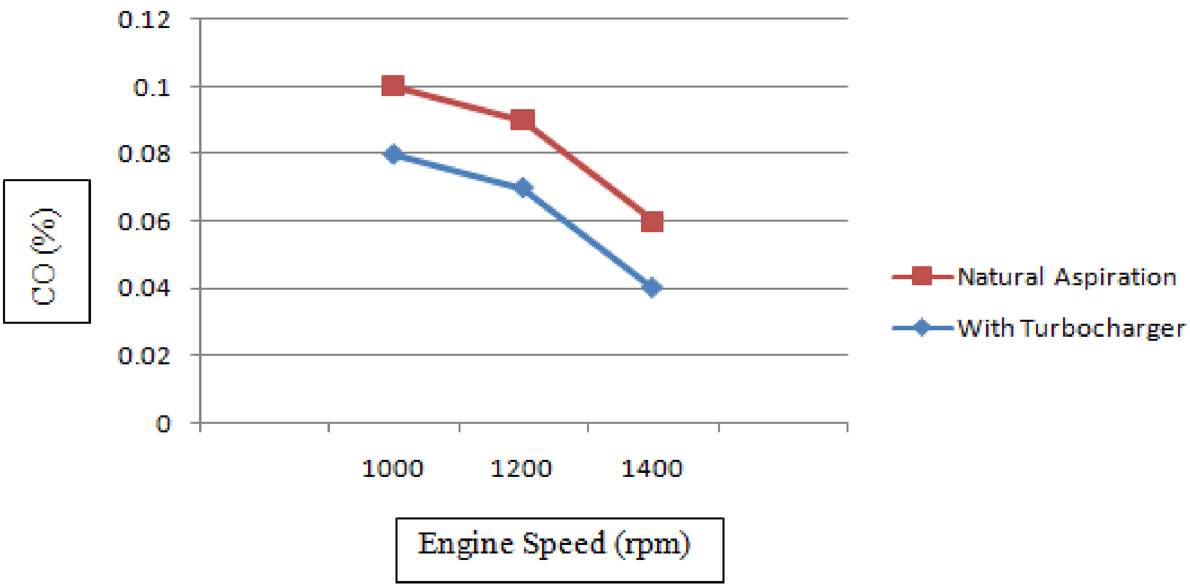

Figure 12. CO Emissions vs. Engine Speed for Max Load

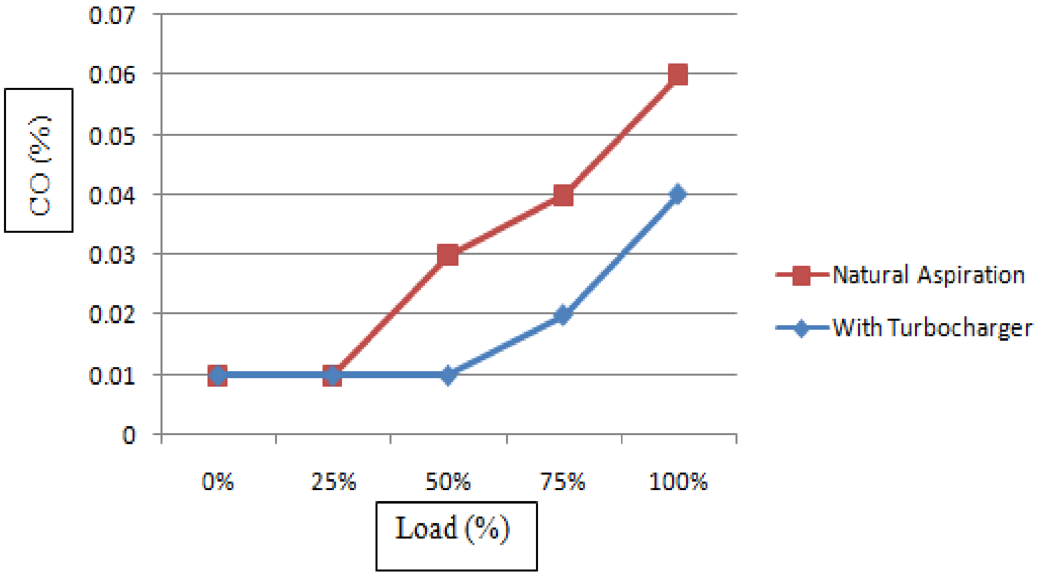

Figure 13. CO Emission vs. Load for Max Speed

CO emissions in CI engines are seen only in traces, usually negligible amounts. The CO emissions of the VGT powered engine were significantly lesser than the naturally aspirated system for max load, except for 1000rpm speed. This slight deviation can be accounted for as a momentary lapse in the emission testing apparatus since the percentage volumes that need to be sensed are tiny.

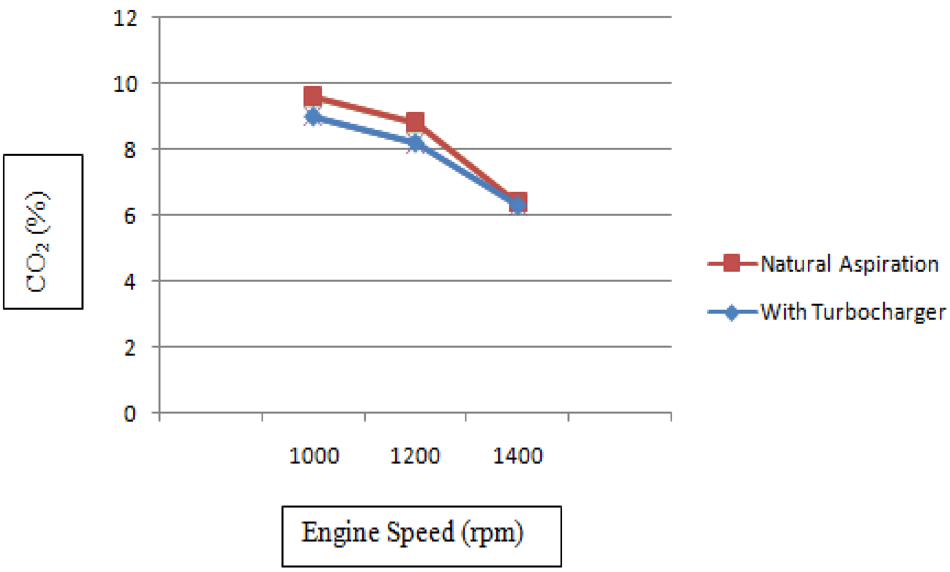

Figure 14. CO_2 Emissions vs. Speed for Max load

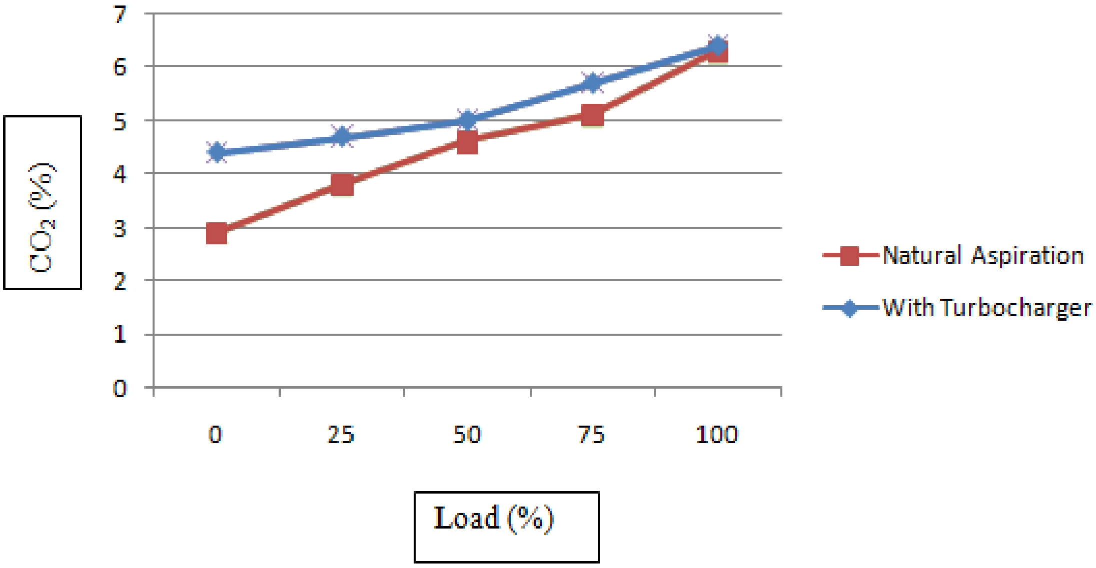

Figure 15. CO_2 emissions vs. Load for Max Speed

The carbon dioxide emissions for the VGT mounted engine compared with the naturally aspirated system, appeared to produce highly inconsistent results. This has caused by a slight oil leak on the turbine bearing causing a spike in the readings at certain points

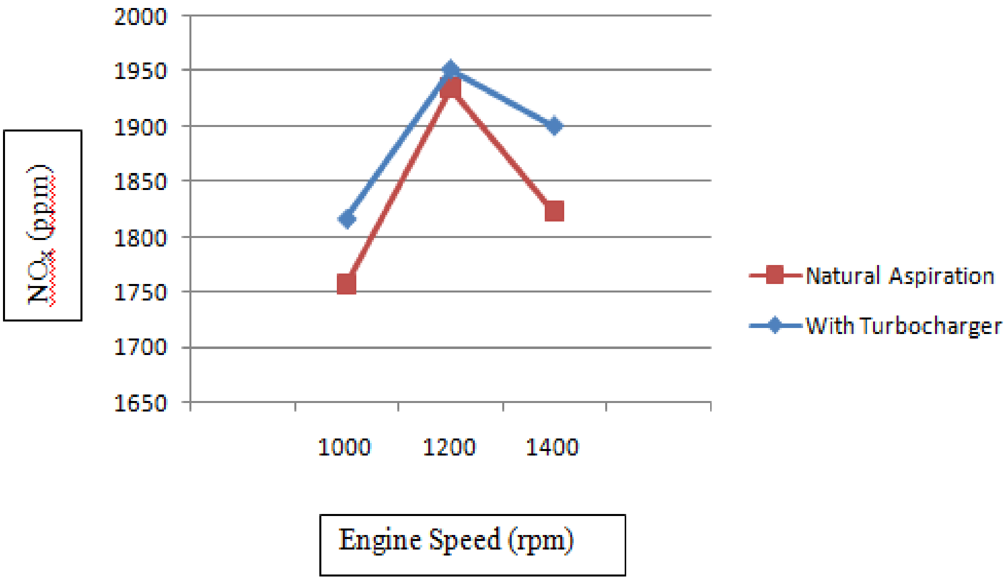

Figure 16. NO_x Emissions vs. Engine Speed at Max Load

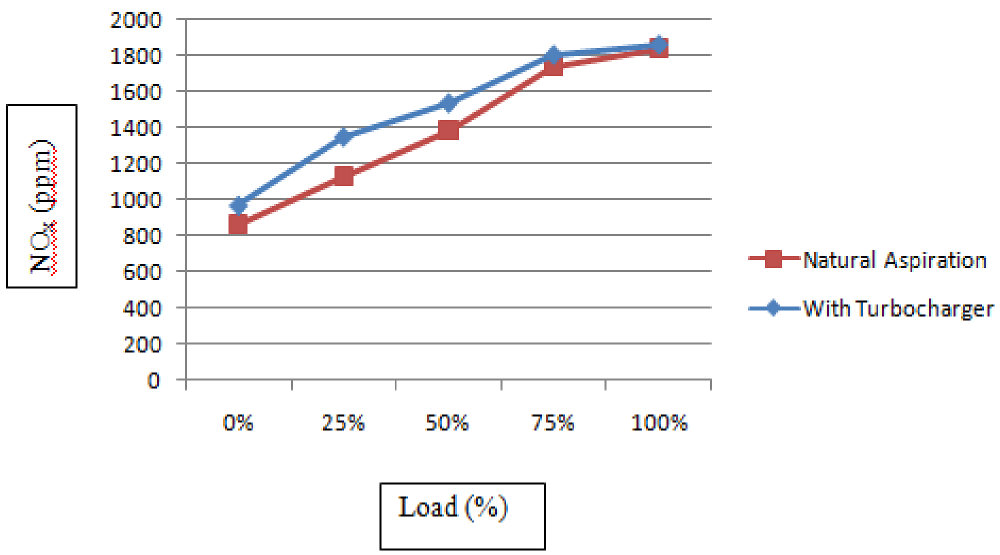

Figure 17. NO_x Emissions vs. Load at Max Speed

From the above graphs, it was observed that the NO_x emissions for the VGT mounted engine were higher than that of the case where the engine is naturally aspirated. The main reason for NO_x emissions in engines is combustion chamber temperature. Because the temperature of gas after compression is naturally higher than that of atmospheric air, the NO_x emissions of the VGT engine were greater. Consistent trend lines suggest that there is no turbo-lag again.

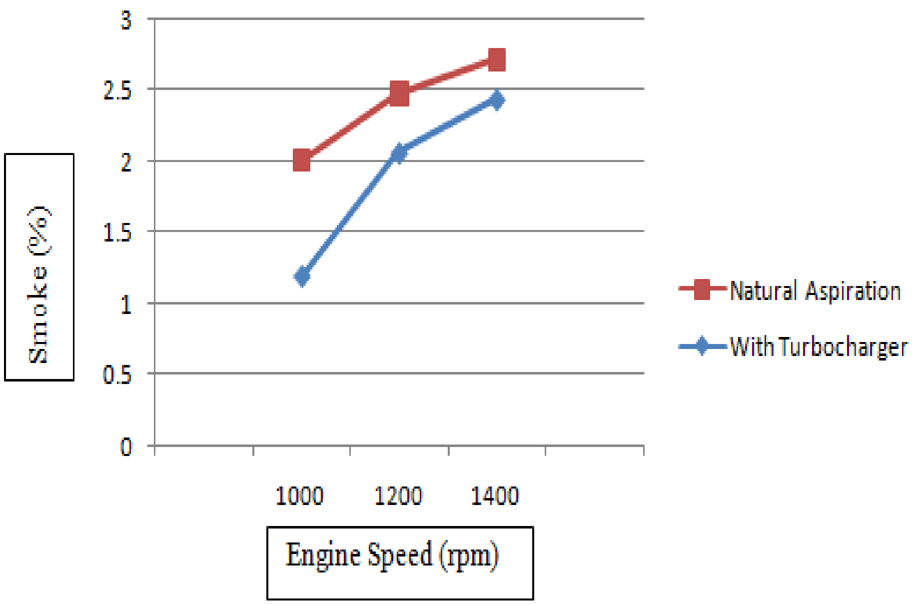

Figure 18. Smoke vs. Engine Speed for Max Load

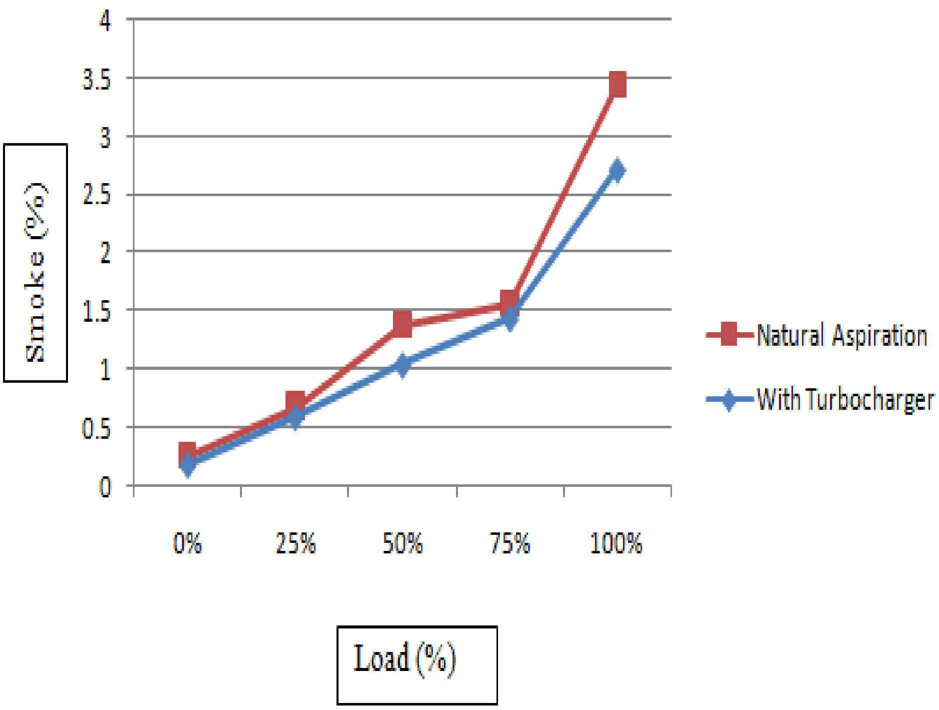

Figure 19. Smoke vs. Load at Max Speed

The graphs above suggest that the values for smoke emissions were overall lesser for the VGT mounted engine compared to the naturally aspirated setup. In this system for better combustion that took place as a result of the dense air that was available after compression by the VGT. Also, the trends suggest the absence of turbo-lag.Taking into consideration the improved values of Brake Power, Volumetric efficiency and reduced Specific Fuel Consumption for all three speeds taken for measurement. It is clear that the impact the Variable Geometry Turbocharger has on the Performance characteristics over an entire range of speed without any turbo lag as in the case of conventional Turbocharger. When Emissions are taken into consideration, it was observed that HC, CO, CO2 and smoke the emission characteristics found for a large part of the speeds was seen to be better than a naturally aspirated engine.Smoke Value at 1400 rpm, CO2 emission at 1000 rpm and NOx for all speeds and loads was observed to be higher than naturally aspirated engines. The higher NOx values can attribute to the higher temperature of the compressed air going into the combustion chamber.This marginal increase in NOx can reduce with more efficient inter cooling

5. Conclusion

This project has successfully analyzed the impact variable geometry turbochargers have on the performance characteristics and emissions of a naturally aspirated CI engine. From the results, the brake power was increased 12% with the use of the VGT. When volumetric efficiency was analyzed, the forced induction capabilities of the VGT enabled the CI engine to breathe more air resulting in a 26% increased of the VGT system compared to the naturally aspirated system. The fuel efficiency of the engine also showed a substantial improvement and this seen in the 25% increase in SFC of the naturally aspirated engine compared to the VGT system. Also, when emissions are taken as a basis of comparison, the max load readings showed a 12.5% decrease in the HC emissions as a result of a complete combustion. The CO emissions for the VGT adapted engine was 33% lesser than the naturally aspirated setup owing to combustion in the presence of excess air and lean mixture. The smoke values for the VGT adapted engines also showed a decrease of 22.3% as a result of better

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combustion. The only drawback of this adaptation is the 2% increase in NO_X emissions which can control by making use of a better intercooler system. However, most of the auxiliary systems used to drive this setup were not adaptations made exclusively on the engine, as future scope for this project, a variable geometry turbocharger system can produce with all the auxiliary systems done to work only on a particular engine to get better efficiencies.

6. References

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