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Studies on influence of Turbocharger on Performance Enhancement and Reduction in Emissions of an IDI CI engine

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ABSTRACT

This paper includes comparison of the performance and emission results obtained by running the IDI CI engine with and without the turbocharger on diesel fuel. A turbocharger can significantly improve an engine horsepower without significantly increasing its weight.

The engine was run at constant rated speed (1000 rpm) and various performance, combustion and emission characteristics were measured at different engine load (25% to 100%) using a loading panel to apply load. A proper test setup was prepared by connecting the engine with Smoke-Meter and 5 Gas-Analyzer. The performance and emission data of the engine was noted at different loads. The performance characteristics (i.e., brake specific fuel consumption and thermal efficiency) were calculated using mathematical relations. The emission characteristics (i.e., smoke opacity, HC, NOx, O2, CO2 and CO) were measured with the help of Smoke meter and 5-Gas Analyzer set-up. The obtained data was plotted on graphs and then compared with each other to give a picture that how a turbocharger fitted to the engine may affect its performance.

KEYWORDS : IDI Diesel Engine, turbocharger, performance, emissions.

1. INTRODUCTION

Due to increase in number of vehicles day by day, the demand of energy is increasing. There is a need of increasing the power output of engine for better fuel economy as well as reduction in harmful emissions such as CO, NO_x, unburnt hydrocarbons and other poisonous gases.

IDI Diesel [1] engines utilize a pre-combustion chamber, sometimes referred to as a pre-chamber. Fuel is injected into the pre-chamber, where it rapidly mixes with oxygen and ignition occurs. As the flame front expands in the pre-chamber, it forces fuel to enter the combustion chamber rapidly, effectively mixing the fuel with air in the cylinder. Sometimes the glow-plug is also located in the pre-chamber to increase the combustion characteristics.

A [2] **turbocharger** is a **forced induction** device used to produce more power by an engine, of a given capacity. A turbocharged engine can be more powerful and efficient than a naturally aspirated engine because the turbine forces more air into the combustion chamber than atmospheric pressure alone. A turbocharger is powered by a turbine that is driven by the engine's exhaust gas. Compared to a mechanically-driven supercharger, turbochargers tend to be more efficient but less responsive.

The turbocharger's compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure [3]. 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 [4].

This paper was concentrated on the performance of a single cylinder diesel engine with and without using turbocharger and to compare results of smoke opacity, NO_x, CO, HC. Performance and emission parameters were studied with and without turbocharger.

For achieving boost in intake air, exhaust flow from engine is used to spin a turbine in the turbocharger and the rotating turbine rotates an air compressor. The speed of rotation of turbine is up to 150000 rpm. The power output of an engine can be increased by increasing the amount of fuel and air it can burn. Engine fitted with a turbocharger burns more fuel by packing more air into cylinders.

When power to spin the turbine is not free, inefficiency arises. The presence of turbine in exhaust increases restriction in exhaust flow. Thus back pressure is generated in exhaust stroke leading to a decrease in power output.

The fitment of turbocharger is made near exhaust where it is connected to exhaust manifold using bolts. Turbine of a turbocharger spins when exhaust gases from engine strike the turbine. A compressor is connected to the turbine using a shaft known as turbo shaft. Compressor is located between the intake manifold and air filter which pressurizes the air going to the piston.

Three essential components of a turbocharger are: Turbine, compressor wheel and housing. First the air is drawn in axially, accelerated to high velocity and then expelled in radial direction. A diffuser is also used which slows down the high velocity air without losses for the rise in both pressure and temperature. The back plate of compressor and a part of volute housing make diffuser. It collects the air and slows it down before it reaches compressor exit.

The operating behavior of compressor is given by maps which show the relationship between pressure ratio and mass flow rate. The centrifugal compressor useable sections are limited by surge and choke lines and the maximum permissible compressor speed.

Some of the automotive turbochargers are provided with a waste gate to reduce turbo lag and to allow the use smaller turbocharger while preventing it from rotating at high engine speeds. The exhaust is allowed to bypass the turbine blades using the wastegate. Wastegate is basically a boost pressure. When pressure is very high, it is an indicator that turbine is rotating very fast, so that wastegate allows some of the exhaust to bypass the turbine blades allowing he blades to slow down.

2. EXPERIMENTAL SETUP

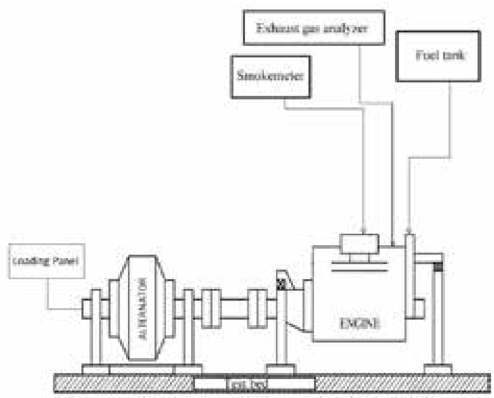

Fig 1: Experimental Setup

The Fig 1 shown is the layout for setup of the experimental study. The setup shows an engine and an alternator coupled together and mounted over a test bed, a fuel tank, a smoke meter, exhaust gas analyser and a control unit. Loading Panel was connected to alternator to vary the load.

a) Engine:

Model Lister	FMS-10 Type IDI
Number of cylinders	1
Swept volume	1580 cc
Compression ratio	17:1
Bore	120 mm
Stroke	139.7 mm
Aspiration	naturally aspirated
Speed	1000 rpm
Power output	7.35/10 kw/bhp
Specific fuel consumption	255 g/kwh

b) Alternator: To apply different loads on the IDI compression ignition engine, alternator is connected with loading panel.

c) Smoke meter: AVL 437 smoke meter is used to determine the smoke opacity of exhaust gases. Its range of measurement is 0-100% smoke opacity. It has an accuracy of ±1% of full scale and a resolution of 0.1%. It measures the smoke opacity in Hartridge smoke units.

d) Exhaust gas analyser: AVL 5-Gas analyser is used to measure exhaust characteristics. It can measure the amount of HC, NOx, CO2, CO and O2 in the exhaust gases. Further, it can measure the stoichiometric ratio.

3. PARAMETERS TESTED

While performing test various performance and emission parameters were calculated and measured according to requirement and availability of resources.

1. Performance Parameters:

a) Thermal Efficiency: It is the ratio of useful output of the engine and the energy supplied (by fuel) to the engine. It is the measure of efficiency of conversion of energy from fuel to the output energy.

b) Brake Specific Fuel Consumption: Amount of fuel consumed for each unit of brake power per hour.

2. Emission Parameters:

a) Nitrogen oxides (NOx) are generated from nitrogen and oxygen under the high pressure and temperature conditions in the engine cylinder. NOx consist mostly of nitric oxide (NO) and a small fraction of nitrogen dioxide (NO2). Nitrogen dioxide is very toxic. NOx emissions are also a serious environmental concern because of their role in the smog formation.

b) Smoke opacity measurement is the only relatively low-cost and widely available method to measure a PM-related emission parameter in the field. For this reason, opacity limits are used in most inspection and maintenance programs for diesel engines. Smoke opacity limits may be also included as auxiliary limits in new engine emission standards.

4. EXPERIMENTAL PROCEDURE

The experiment was conducted with varying load ranging from 0-100% with a step of 20% increment on a constant speed engine. Engine was coupled with an alternator subsequently with loading panel. Further engine was connected to AVL make smoke meter and 5 gas analyser to measure the smoke in Hartridge smoke units and CO, CO_2, O_2 by volume and HC, NO_x with ppm respectively. It was ensured that the engine was run for given specific time before measuring the emissions. Gravity based burette system is used to measure the fuel consumption. Baseline data was generated without turbocharger with conventional diesel and compared the same with turbocharger data. Proper care was taken to mount the turbocharger with the exhaust and inlet of the engine in order to maintain minimum back pressure in the exhaust manifold.

5. RESULTS & DISCUSSION

A lower bsfc (about 5% lesser) and higher thermal efficiency (about 8-9% higher) is obtained by using a turbocharger. Moreover, a reduction in emissions is also obtained in a turbocharged engine compared to the naturally aspirated engine. A decrease in smoke opacity (about 14%) is obtained at higher loads of 50-75%.As combustion is proper in case of turbocharged engine due to adequate air available, carbon particles in smoke are reduced. NOx emission is more (about 27% rise) in turbocharged engine as adequate air is available for combustion and temperature of combustion chamber is also high. CO emission is reduced (about 33% drop) with the implementation of turbocharger as most of the CO produced after combustion is converted into CO_2 due to reaction with plenty oxygen available leading to higher CO_2 emissions.

5.1. Brake Thermal Efficiency:

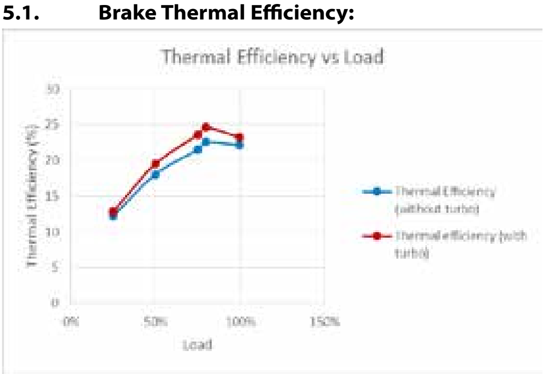

Fig 2: BTE vs Load

Fig 2 shows that the brake power of a turbocharged engine is more resulting in increased thermal efficiency of the engine. The Brake Thermal Efficiency depends on the brake power of the engine. The efficiency of turbocharged engine is observed to increase by 8-9%.

5.2. Brake specific fuel consumption:

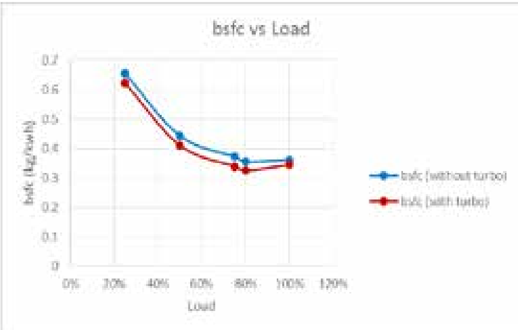

Fig 3: bsfc vs Load

The amount of fuel consumed by the engine increases with the increase in load. Bsfc is initially high and then drops, levels at medium loads and again increases at higher loads. At lower loads the bsfc is high because the combustion efficiency is poor and the amount of heat loss to the combustion chamber walls is greater at higher load and higher inertia forces. In a turbocharged engine, bsfc is about 5% less as compared to naturally aspirated engine at all the loads, as brake power generated is more.

5.3. Smoke Opacity:

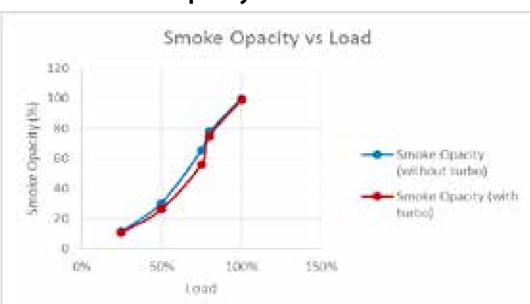

Fig 4: Smoke Opacity vs Load

Smoke opacity of exhaust is the measure of amount of light blocked by the smoke. It is a measure of optical properties of diesel smoke indirectly measuring diesel particulate emissions. 'Smoke limited brake power' is the term used to denote the load for an engine at which smoke opacity is 100%. Smoke opacity increases with increase in load because of the more fuel being consumed inside the engine. The smoke opacity decreases by 14% using a turbocharger at loads of 50-75% as compared to the result obtained in case of natural aspiration. However, at higher loads, result obtained is same.

5.4. HC Emissions:

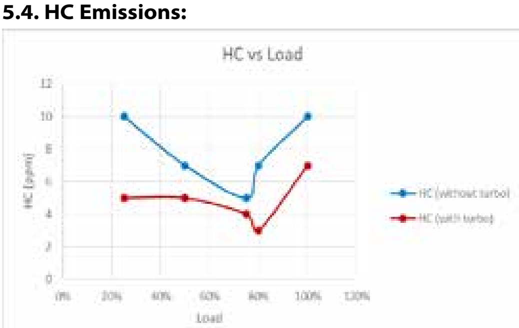

Fig 5: HC vs Load

As the load gets increased the HC emissions increases drastically. The reason behind this is, at higher loads the availability of Oxygen gets reduced as more amount of fuel is injected into the engine cylinder, resulting in improper combustion & more un-burnt HC emissions. Hydrocarbons emitted due to incomplete combustion result in smog which is major problem in metro-cities. In naturally aspirated engine, HC emission is more due to the lack of air resulting in incomplete combustion. In a turbo-charged engine, plenty of compressed air is available resulting in proper combustion of fuel which reduces HC emissions. At 25% load, a drop of 50% in HC is observed in case of turbocharged engine. As the load rises from 50-100%, a reduction of about 25% in HC emission is observed.

5.5. NO_x Emissions:

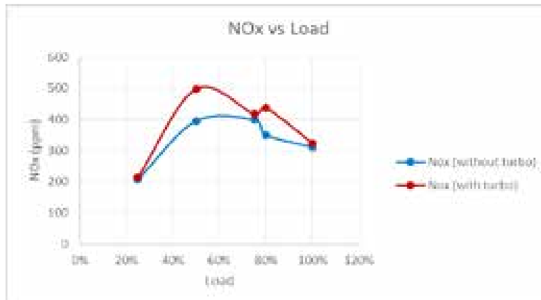

Fig 6: NO_x vs Load

Nitrogen oxides (NOx) is basically a combination of NO & NO2. They are produced when nitrogen and oxygen gases react during combustion at high temperatures. In excess of air, NO_x emitted is more due to increased reaction of nitrogen with oxygen. Thus, in a turbocharged engine, NO_x emission is more due to availability of more compressed air and increased reaction of nitrogen and oxygen. It is similar at 25% load. NO_x increases by 27% at loads of 50-75% in case of turbocharged engine. At 100% load, there is an approximately 4% rise in the NO_x with turbocharger.

5.6. CO Emissions:

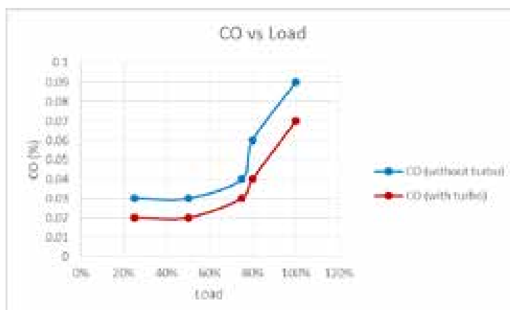

Fig 7: CO vs Load

Carbon Monoxide is toxic gas which is colourless, odourless and tasteless and slightly less dense than air. It is highly toxic as it forms carboxy haemoglobin in blood resulting in choking. Carbon Monoxides are formed when there is no adequate availability of oxygen inside the chamber, resulting into partial oxidation of HC in the exhaust Manifold. With the use of turbocharger, CO emission decreases by about 33% at all the loads as more CO produced in combustion is converted into CO_2 after reacting with oxygen due to more compressed air availability in inlet.

5.7. CO_2 Emissions:

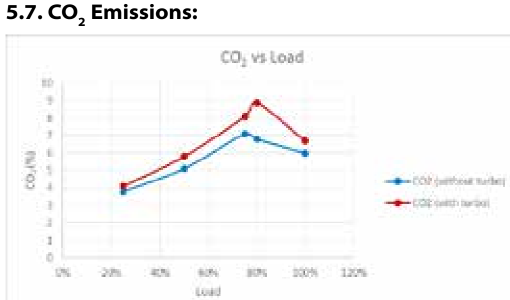

Fig 8: CO_2 vs Load

CO_2 is formed as a by-product of combustion when sufficient oxygen is available. CO produced after combustion reacts with oxygen to form CO_2. It is comparatively less toxic than CO but results in greenhouse effect. The use of turbocharger increases the amount of air available and thus CO produced reacts with oxygen to form CO_2 resulting in increase of CO_2 emission as compared to naturally aspirated engine. An 8% rise in CO_2 content is observed at 25% load. This rise is about 14% at 50-75% loads. At 100% load the CO_2 is higher in case of turbocharged engine by about 11%.

6. Conclusion

From the results it is observed that the performance obtained in case of turbocharged engine is much efficient as compared to the naturally aspirated engine. A lower bsfc (about 5% less) and higher thermal efficiency (about 8-9% higher) is obtained by using a turbocharger. Thermal efficiency obtained is more in case of a turbocharger as power available is more due to the availability of oxygen and proper combustion of fuel. Moreover, a reduction in emissions is also obtained in a turbocharged engine compared to the naturally aspirated engine. A decrease in smoke opacity (14% lesser) is obtained at higher loads of 50-75%. As combustion is proper in case of turbocharged engine due to adequate air available, carbon particles in smoke are reduced. NOx emission is more (by about 27%) in turbocharged engine as adequate air is available for combustion and temperature of combustion chamber is also high. CO emission is reduced (by about 33%) with the implementation of turbocharger as most of the CO produced after combustion is converted into CO_2 due to reaction with plenty oxygen available leading to higher CO_2 emissions (about 11% higher at 100% load).

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