JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1680 - 1688
https://publishoa.com
ISSN: 1309-3452

Performance investigation and comparison of single cylinder four stroke diesel engines with super, turbo, and tri-charger

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ABSTRACT

The current study focuses on the influence of various boosting technologies as well as a comparative examination of single-cylinder four-stroke diesel engines. The experiment was conducted out on a single-cylinder 4-S VCR diesel engine with a crank-driven supercharger, turbocharger, and Tri-charged, which combines the turbocharger, crank-driven supercharger, and electric-driven supercharger system. Because the crank-driven supercharger uses engine power and the turbocharger has turbo-lag, the tri-charged system is used. The trials were carried out at a constant speed of 1500 rpm and a varied loading capacity of 0kg to 12kg at 2 kg intervals. The results increased the volumetric efficiency (VE) of the tri-charger from 81.17 to 122.35 percent. It is also raised in super and turbo running modes. Tri-charging lowered the BSFC from 0.36 Kg/Kwh to 0.31 Kg/Kwh, while thermal brake efficiency rose from 31.34 percent to 32.97 percent when compared to a traditional engine. The tri-charged method also helps to reduce pollution. The CO level dropped from 0.12 percent to 0.07 percent. NOX IS rises from 1015 ppm to 1210 ppm due to super, 1268 ppm due to turbocharger, and further lowered to 1128 ppm owing to super and turbocharger, although higher than conventional. This rise in NOx is caused by the increase in combustion temperature caused by the boost charger. Thus, the findings show that a tri-charged system is optimum for single-cylinder diesel engines in terms of performance enhancement and fulfilling rigorous emissions standards with emission reduction.

Keywords: Conventional, Supercharged, Turbocharged, Tri-Charged Engine, Emission Analysis

1. INTRODUCTION

The key problems for automakers are efficiency, power, and emission reductions such as NOX, CO, and HC [1]. The transportation industry, through bulky cars, is responsible for total greenhouse gas emissions due to insufficient decarburization of the combustible product [2]. The most effective way to pick up engine performance is to use a multi-stage boosting system that does not require any changes to the engine architecture. The multi-stage density increasing system consists of more than two chargers arranged in a system structure that improves engine capacity and fuel economy [3]. To compensate for the lag in turbo, a crank-driven supercharger was installed. As soon as enough thrust was generated, the crank-driven supercharger was disengaged, and boosting via the electric-driven supercharger was triggered to compensate for the boost and power loss [4]. EGR, WHR, and biodiesel are among the several boosting technologies used [5]. A turbo charging technology is an excellent alternative among several boosting tactics [6], but it does not respond at no and low load capacity. As a result, a twin-turbocharger with LP and HP turbochargers is employed [7]. It has a better grip than comparable types, although it is more difficult to install [6]. The third kind is a super-turbo layout, which places an LP supercharger on the crankshaft for ease maintenance and installation. [7-8]. Modifying a three-charged system overcomes the problems of and turbo-lag and power loss. Choose a turbocharger that is adequate for the engine size [9-10]. Selected turbochargers have a high or low capacity, causing the engine to run unevenly and produce poor power. [11-13].

According to Feng Y. et al. [14], the intake pressure is momentary at low engine speeds about 2000 rpm and becomes steady-state at roughly 4000 rpm. The use of a turbocharger alone at low engine speeds, on the other hand, is inefficient and results in higher NOx emissions due to high intake temperature. At low engine speeds, however, using a turbocharger alone is ineffectual and produces more NOx. It is also necessary to use an additional cooling system [15-16]. Additional pipes are required as a result of incorporating an intercooler or radiator, making engine building more challenging [17]. Turbochargers are used in all of the systems listed, and the most important issue with turbochargers is turbo-lag caused by low thrust [18-19]. A variable geometry turbocharger was developed by Song K et al. [20]. (VGT). By altering angles to manage exhaust gas flow on turbine blades, fixed vanes replace moving vanes in VGT to increase mass flow of air and fuel consumption [21]. The velocity of the exhaust gas is lower in VGT because to the larger flow area, and hence the intake boost is lower at low and middle engine speeds. Another downside of VGT is that it delivers poor acceleration from a standstill and raises the engine's total cost [22]. Because of higher input pressure and lower pumping losses, the turbine expansion ratio increases

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with power augmentation [23-24]. Pumping losses were decreased by using a turbocharger with an EGR system [25-26]. In order to reduce NOx emissions, the exhaust gas recirculation system is engaged at a rate of 5%. [27-29]. As a result, a supercharger is an excellent candidate for use in combination with a turbocharger, and it can be placed in two ways: mechanical crank driven and electric powered [30-32], with the mechanical driven consuming engine output power. Zhu et al carried out an experimental assessment of a high-pressure multi-stage boosting system, i.e., a turbo-super system, at various pressures demonstrates that utilizing a supercharger with ideal throttling conditions increase the fuel efficiency [33-35, 36]. Buchman et al. [37] described a method for turbocharging that featured the addition of an air capacitor between the intake manifold and turbocharger compressor [38, 39] Koniuszy and colleagues At the moment, the Indian government is accelerating the adoption and manufacturing of electric vehicles (EVs), with the goal of making India an all-EV market by 2040 [40]. However, due to a lack of EV infrastructure, EV adoption is rather challenging. [41]. Currently most of the EVs uses lithium-ion batteries, which are prohibitively expensive, limiting long-distance driving and having a four-year life expectancy. As a result, due to a lack of charging infrastructure, the deployment of EVs in India would take a long time [42]. This is due to the fact that agricultural activities such as harrowing, rotary harrowing, ploughing , sowing, and rolling demand torque larger than 300-400 N-m for tractors and trucks [43-45].

It is obvious from the preceding literature that much effort has been expended to increase performance on multi-cylinder diesel engines using stand-alone superchargers and turbochargers or a grouping of super-turbo with varying layouts. There is space for development of the tri-charged system to fulfill demand, mainly for a single-cylinder engine, which results in better brake power, decreased fuel consumption, and lower NOX emissions. The current study evaluated the performance of a single-cylinder diesel engine to that of a supercharged, turbocharged, and tri-charged engine at a constant speed of 1500 rpm under loading conditions ranging from 0 kg to 12 kg. The emissions and performance of the engines have been measured.

2. EXPERIMENTAL SETUP AND PROCESSES

The tests are conducted at Apex Innovations Pvt. Ltd.'s specialised Research Associated Lab (RAL) (Engine Test Setup, Computerised-224 model) in Sangali, Maharashtra, India, as seen in Fig 1. The test setup includes all of the necessary instruments for monitoring engine performance metrics such as BP, BTHE, VE, BSFC, combustion pressure, and crank-angle, among others. Emission measurement instruments are also used to measure HC, CO, NOx, and other pollutants. It is also possible to integrate airflow, fuel flow, temperature, and load monitoring. A belt and pulley system connects the crank-driven supercharger to the cranking shaft at the engine's rear side, transferring power from the crankshaft to the blower. Turbocharger connected to the exhaust pipe.

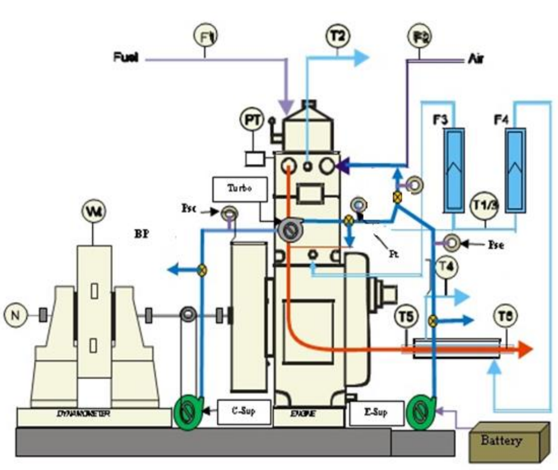

Fig. 1 Tri-charged Experimental Layout

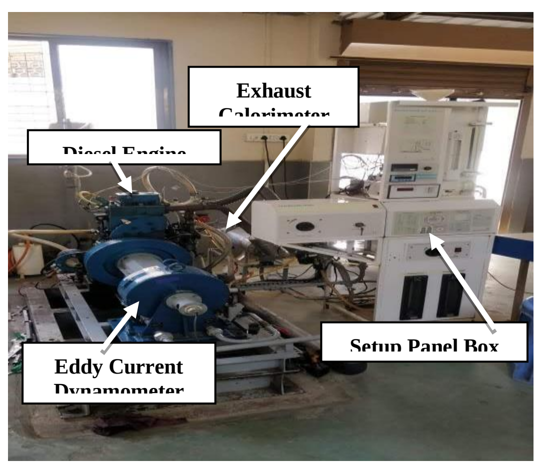

Fig.2 Experimental Setup

An electrically driven supercharger is one that is powered by a battery. An orifice-type flow control valve with a 50% opening regulates the flow rate. The impact of supercharging was tested at an adequate flow rate. A crank-driven supercharger, exhaust gas driven turbocharger, and an electric-driven supercharger are all combined in the tri-charged assembly. A perfectly constructed Y-type connection is used, with ambient air compressed and fed by an electrically charged supercharger at one end of the Y and air from the exhaust-driven turbocharger taken via the other. A supercharger and a turbocharger work together to make available boost air to the engine. In this example, two superchargers (c-super and e-

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super) are working in tandem with a turbocharger.

3. RESULT AND DISCUSSION

The concert assessment and emission study performed on the naturally aspirated engine have been compare with the crank driven supercharger, e-supercharger, turbocharger, and tri-charger in this part

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3.1 Effects on brake specific fuel consumption: [BSFC]

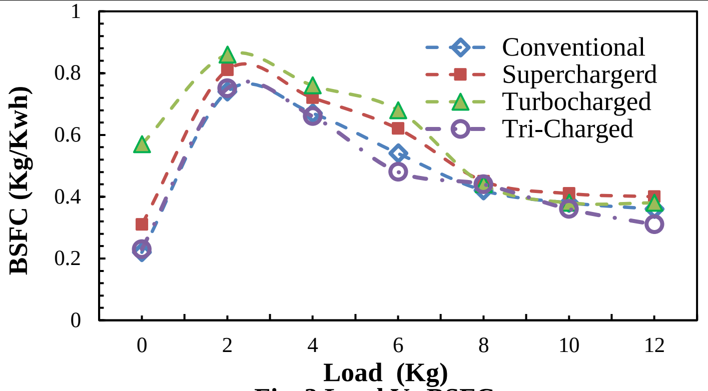

Fig. 3 Load Vs BSFC

Fig. 3 demonstrates the variation of BSFC with engine loads, with the lowest BSFC value indicating engine efficiency. The optimal BSFC for a CI engine is around 0.2 Kg/Kwh. The BSFC of a normal engine with no load is 0.22 Kg/Kwh, which climbs to a maximum of 0.57 Kg/Kwh at 2 Kg when employing a turbocharger owing to turbo-lag. In addition, when the supercharger is used, the BSFC rises to 0.31 Kg/Kwh. However, it is roughly the same in tri-charger mode. At 12 kg load, the supercharger initially boosts the BSFC from 0.36 Kg/Kwh to 0.4 Kg/Kwh and 0.38 Kg/Kwh by the turbocharger; however, the tri-charger reduces it to 0.31 Kg/Kwh.

3.2 Effects on brake thermal efficiency: [BTHE]

Thermal efficiency is an important characteristic for engine performance; it is the amount of fuel used to generate power. The use of superchargers and turbochargers increases fuel consumption. As a result, as compared to a standard engine, the supercharger dropped brake thermal efficiency from 31.34 percent to 27.68 percent while turbochargers reduced it to 29.67 percent. However, as compared to the traditional engine, BTHE rose from 31.34 percent to 32.97 percent owing to tri-charger optimization of fuel charge due to intake air boosting with the help of an electric supercharger. (Figure 4)

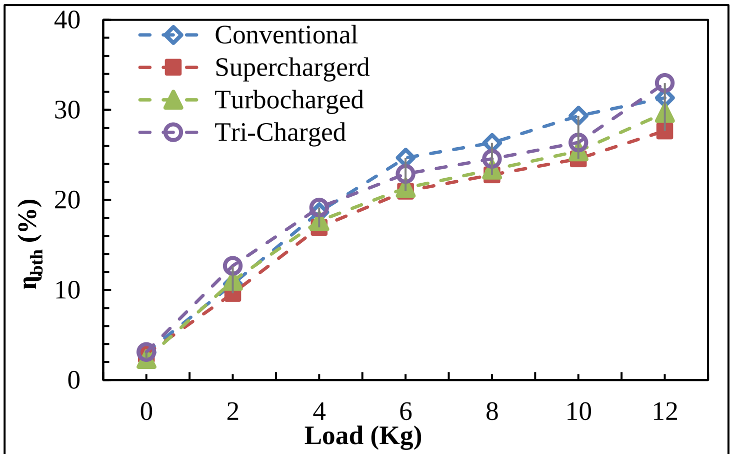

Fig. 4 Load Vs η_{bth}

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Volume 13, No. 2, 2022, p. 1680 - 1688
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3.3 Effects on volumetric efficiency: [VE]

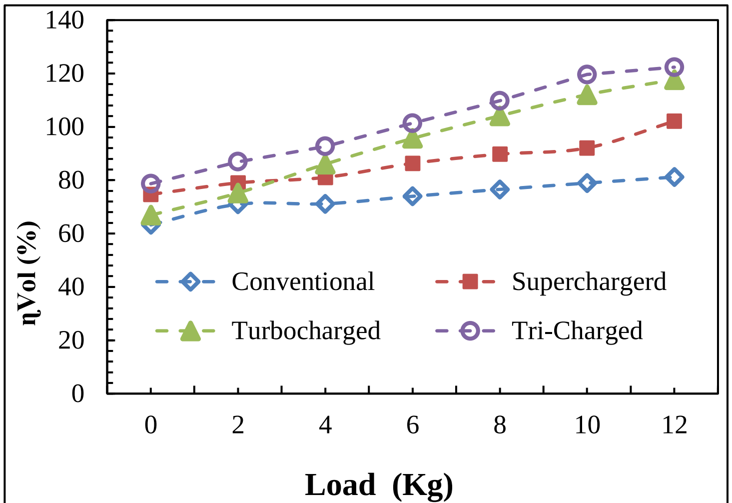

Fig. 5 Load Vs. ηVol

The volumetric efficiency (VE) is simply the relation of the mass concentration of the air pulled into the cylinder to the mass density of the same air at the intake manifold. The testing results indicated that, when compared to a normally aspirated engine, volumetric efficiency is higher in all operating circumstances. When operating at 12 kg of load capacity, the VE climbed from 81.17 percent to 102.11 percent using a supercharger, to 117.67 percent using a turbocharger, and to 122.35 percent using a tri-charger. This rise in VE is the result of higher intake pressure caused by supercharger and turbocharger boost. (Fig. 5)

3.4 Emission Characteristics of CO (%Vol.)

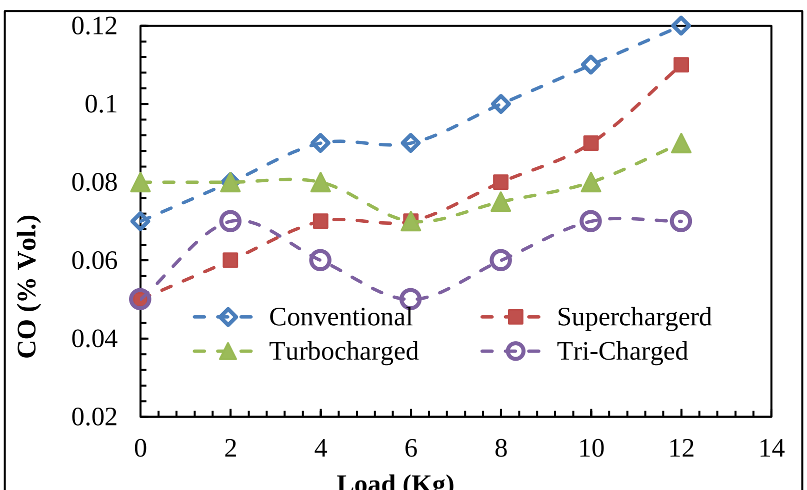

Fig. 6 Load Vs CO

A conventional engine produces more CO than a turbocharged, supercharged, tri-charged engine (Fig. 6). CO emissions are greatly decreased when turbo, super, and tri-charged engines are used. The turbocharger raises the CO at no load from 0.07 percent vol. to 0.08 percent vol. owing to decreased trust in the turbine blades. The CO is lowered from 0.12 percent vol. to

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0.11 percent vol., 0.09 percent vol., and 0.07 percent vol. at 12 kg load owing to the supercharger, turbocharger, and tri-charger, respectively.

3.5 Emission Characteristics of NO_X: (PPM)

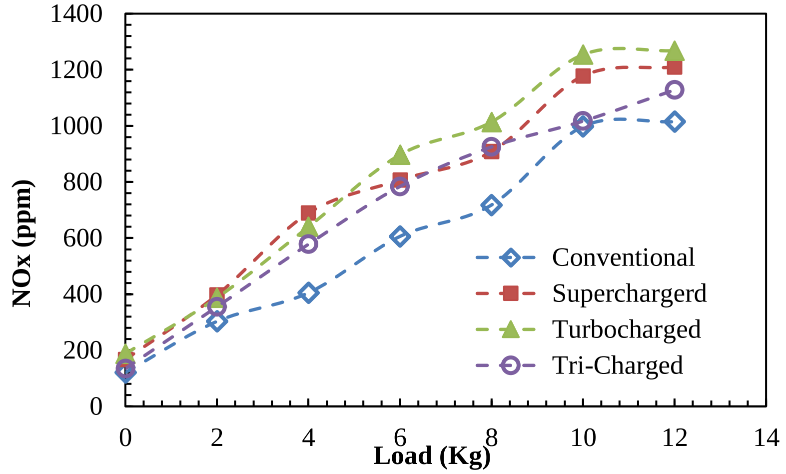

Fig. 7 Load vs NOx

The characteristics of load (W) vs. NO_X emissions are depicted in Fig.7. It is obvious that at low load capacity, NOX levels rise from 121 ppm to 167, 188, and 135 ppm owing to super, turbo, and tri-charger operation. NOX, on the other hand, is raised in pat and a full load of 6kg and 12kg. At full load, it rises from 606 ppm to 807, 897 ppm when compared to a standard engine; however, it falls to 784 ppm when compared to super and turbocharged. At 12 kg load, NOX climbed from 1015 ppm in the conventional engine to 1210 ppm in the supercharger, 1268 ppm in the turbocharger, and 1128 ppm in the tri-charger. As a result, NOX increased owing to air boosting technologies such as superchargers and turbochargers; however, it decreased due to the use of tri-chargers.

4. CONCLUSIONS

The influence of turbocharged, supercharged, and tri-charged engines on performance and emissions was explored in this experimental investigation. The naturally aspirated engine performance was used as a baseline for comparison with supercharged, turbocharged, and tri-charged modifications. The following findings have been reached.

- The test findings for naturally aspirated engines reveal that the BSFC is smaller than all modified cases at no load and at lower load capacity, but consistent at full load. Thus, normal engine performance is favourable at no and partial load capacity, however upgraded systems like super, turbo, and tri-charged might be helpful at full capacity.
- Under variable loading conditions, the centrifugal-type supercharger can compress and supply high density air at an appropriate mass flow rate and pressure ratio while retaining high adiabatic efficiency.
- In the case of BTHE, it is proven to be constant at all loads and improved by 1.71 percent at maximum load. Because the supercharger is attached to the crank, it rotates at the same speed as the output shaft. As a result, thermal efficiency improves when compared to traditional engines, however not as much as turbo and tri-charge engines.
- CO emissions are greatly decreased by super and tri-chargers under low load, but turbochargers emit more. When the engine is running at utmost power, the CO levels are lower in all modes of boosting technology (super, turbo & tri-charger).
- • NOX emissions are increasing owing to the usage of boost systems; this is due to an boost in combustion

temperature as a result of density increase. The NOx is higher in the super and turbo modes compared to the ordinary engine, but it is further decreased by the use of a tri-charger vs the super and turbocharger. As a result, tri-charger boosting is a better alternative than super and turbo boosting.

- The tri-charger can lower NOX emissions by providing low-temperature air to the engine at a natural temperature and pressure.
- In addition, the supercharger was removed from the crankshaft and a GT 30 Turbocharger was installed in the engine's exhaust manifold. During testing on a standard engine, the exhaust-driven turbocharger produced encouraging results, with a progressive drop in power.
- A battery-powered electric driven supercharger compresses the air, which is then combined with the turbocharger's twin-charged (Crank Super + Exhaust Turbo) air. This mixing is done to compensate for pressure loss due to increased expansion as well as temperature rise due to coolant oil accumulation. It has been revealed that the supercharger gets disengaged or inactive once the turbocharger reaches a suitable speed, and therefore in most situations it is considered to be twin-charged but acts as a single turbocharged system; consequently, in this study, a tri-charged system was designed to bridge that gap.

5. ACKNOWLEDGEMENT

The authors acknowledge University of Mumbai for financial support through sanctioning minor research proposal in this study. Grant No: APD/24/of 2016-17 Dated 18th March 2017. With Project No: U 45

6. OUTLINES OF PAPER

- Experimental investigation and emission analysis are successfully conducted on single cylinder four stroke diesel engine using combined tri-charged system
- Tri-chartering has great impact on engine efficiency and emissions.
- Tri-charged system leads to higher flow rate and fuel consumption.
- Impact of power driven supercharger, battery powered supercharger and exhaust driven turbocharger, and all driven tri-charger on engine performance are qualified.

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