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Performance Enhancement of Internal Combustion Engine Using Weight Reduction Approach

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ABSTRACT

The purpose of this study is to investigate and enhance the performance of the single cylinder 4- stroke water cooled diesel engine using weight reduction approach. Initially, the existing engine of 3.7 kW (5 hp) was tested for performance analysis as per the method mentioned in IS 11170 for loop test by altering its speed then an engine was critically studied for weight reduction possibilities and modified accordingly. The modified engine has been tested again following the similar method. The various performance and emission parameters of both the engines at their most suitable speed were measured and compared. From the result, it was concluded that the modified engine shows better result from performance and emission aspects along with better mobility and convenience at a reduced cost. However, the modified engine needs strong base plate as a foundation because of little higher speed.

Keywords: Four-stroke diesel engine; weight reduction; performance analysis; emission aspects

INTRODUCTION

Owing to their excellent drivability and fuel economy, diesel engines are the most common internal combustion engines that are widely used in various sectors such as agriculture, transportation, and industry. Rajkot is one of the leading center and hub for manufacturing and assembling of various automobile parts and all types of diesel engines which are used for various applications in the field of irrigation, small capacity generator set and agriculture.

Referring to the results of a recent survey conducted, there will be a phenomenal rise in energy consumption in coming years which will worsen the energy scenario and increase the importance of performance and emission aspects [1-3]. Therefore, the engine manufactured by local manufacturers for agriculture are to be tested as per IS:11170:1985, i.e. Indian standard for performance aspects of diesel engine used in the agriculture field with rated brake power less than 19 kW.

However, this standard is not covering any requirements related to emission aspects. Considering performance and emission as key criteria for survival, this industry is facing strong competition in the international market. Therefore, it is decided to study and investigate this issue by conducting an experimental analysis of selected engine from performance and emission aspects. It is also felt that as the selected engine is specifically used in the field of agriculture it should be light in weight for better mobility and convenience, therefore weight reduction possibilities have been investigated. This paper presents a detailed study which covers performance and emission improvement of the single cylinder four stroke water cooled engine following weight reduction approach. Results obtained were also compared.

Performance and emission enhancement in the diesel engine is not a new concept. Lot of work has been done in this aspect of a diesel engine. The various authors have studied and suggested different methods for achieving this objective. In diesel engines, significant research efforts [4, 5] have been conducted in direction of using various blends of biodiesel as fuels. It might be because of the fact that the fuel characteristics of biodiesel are approximately the same as those of fossil diesel fuel and thus it can be used directly in the engine without any major modification.[6, 7].

Considerable reductions in the emission of various emission elements like CO, SO_X smoke, and particulate matter are observed while using various type of biodiesel in a diesel engine as a fuel [8, 9]. Jaichandar and Annamalai [10] conducted the experiment on single cylinder four stroke constant speed engine at different loading condition using methyl ester biodiesel as a fuel. It was observed that although there was a slight increase in BSFC and a corresponding decrease in thermal efficiency, the considerable reduction in emission parameters like CO, HC, and smoke. Neyda et al. [11] worked on a study of various biodiesel proprieties and indicated that among the different vegetable oils jetropha curcas oil has some good characteristics, such as higher cetane number, less dense, higher oxygen content, lower acidity, better oxidation stability and suitability for storage. Dubey and Gupta [12] performed the experiment to identify the performance of a combination of Jetropha biodiesel and turpentine oil in diesel engine under different loading conditions, this combination found superior from the emission point of view as at full load condition, considerable emission reduction of CO, $NO_{X,}$ and CO_2 was observed. Azad et al. [13] evaluated performance and emission characteristics of multi-cylinder diesel engine with soybean and waste oil biodiesel fuels. The results indicated that thermal performance of the engine decreases slightly with an increase in biodiesel blend; however, emission decrease with increase in biodiesel blends. Further, it was observed that waste oil biodiesel showed a better trend of emission reduction as compared to soybean biodiesel.

Several studies have evaluated the effect of injection timing, pressure, and duration on performance and emission of biodiesel blended diesel engine [14-18]. Liang et al. [19] identified the impact of the various factors like pressure, timing and duration of combustion on the performance of the engine. On the basis of the results, he concluded that higher combustion pressure, longer duration of combustion and advancement in timing was desirable for the better engine performance however the author took the biodiesel as a fuel, but the same results are applicable to the engine running on conventional diesel. Rostami et al. [20] studied the effect of fuel injection timing on engine performance at different speed. The results indicated that advancement in injection timing led to decrease in the BSFC and exhaust temperature, which lead to increase in the performance. Sathiyamoorthi and Sankaranarayanan [21] investigated the effect of advancement in injection timing on performance and emission of direct injection diesel engine fueled with different blends of lemongrass oil and observed that optimal injection timing for that engine was 27° BTDC as a noticeable gain in performance and improvement in emission was obtained with this timings.

However, it was observed that using biodiesel as fuel in existing engine resulted in slight power loss, lower thermal efficiency and higher emission of nitrogen oxides [22-24] This might have happened because of the fact that the formation of NO_X is highly dependent on in-cylinder temperature, the oxygen concentration and residence time for the reaction to take place [25]. Detailed study of a literature review [26] emphasized that most responsible factor for CO emission is the absence of excess oxygen in fuel. Some other important factors which are responsible for the CO emission are air/fuel ratio, injection timing, engine speed, injection pressure and fuel characteristics [27]. In this connection, Chauhan et al. [28] studied the effect of loading condition on NO_X and CO emission. There was an increase in NO_X emission linearly with the load because of higher combustion temperature at higher load which is considered as a most important factor for the emission of NO_X.. This study also found that at higher load the amount of air remains same, but fuel quantity increased which resulted in higher CO emission, therefore, CO emission also increase linearly with the load. However, Abdelrahman [29] in his research mentioned that in a diesel engine, rich mixture exists locally even if excess air is present in the combustion chamber and combustion may be poor due to a lower temperature at no load condition which might be the reason of higher CO emission at no load condition.

İçıngür and Altiparmak [30] evaluated the effect of fuel cetane no and injection pressure on diesel engine performance and emission. They mentioned that engine torque and power at maximum torque speed were increased by 5 and 4% respectively with increasing cetane no of 46 to 54.5. However further increase was not resulted in significant change in performance. NO_X emission was reduced by 10 % with an ncrease in cetane no from 46 to 61. Semin et al. [31] investigated the effect of fuel injection pressure (FIP) on performance and fuel consumption of diesel engine at fixed load with various speeds. The experimental results obtained showed that, increasing the fuel injection pressure resulted in a higher value of IHP and BHP at higher speed. However, the value of SFC decreased with increase in the FIP from 180 bars to 200 bar only when the speed of the engine was higher than 1000 rpm. Some studies mentioned [32, 33] that higher FIP improve fuel air mixing which resulted in faster combustion that directly influences the emission aspects. Zhang et al. [34] observed that increase in FIP leads to improved air-fuel mixture formation which ultimately reduces smoke and CO emission. Radha et al.[35] analyzed the effect of varying injection pressure and injection timing simultaneously on four stroke, single cylinder, constant speed, water cooled diesel engine fueled with three different vegetable oils. It was observed that the performance of jojoba methyl ester found superior for higher injection pressure with minimum emission. Agarwal et al. [36] observed the effect of fuel injection on emission and performance of single cylinder diesel engine and they achieved the improvement in performance and emission by lowering the FIP at higher speed.

Modifications in compression ratio, EGR, injection process and parameters [37] have a significant impact on engine power, efficiency and exhaust emissions. Shahadet et al. [38] examined the combined effect of EGR and inlet air preheating on engine performance and concluded that at medium load condition NO_X and CO emission along with BSFC decreased when inlet air preheating and EGR were applied together. Ravikumar et al. [39] analyzed the effect of compression ratio and EGR on performance, combustion, and emission of a diesel engine. The test was conducted at different compression ratios with different loads and for different EGR rates. The results indicated that the increase in compression ratio resulted in higher brake thermal efficiency. Increase in the brake thermal efficiency by 13.5 % and reduction in NO_X emission by 11 % was observed with increase in EGR percentage. Laguitton et al. [40] examined the effect of CR on the emission of diesel engine The results of a study indicated that, although there was a small CO and HC penalty, either reducing the CR or decreasing the IT greatly reduced OP and NO_X emission.

Canakci et al. [41] analyzed the effect of speed on various engine parameters and claimed that speed is one of the important parameters for improvement in performance and emission aspect because it positively affects the turbulence level of air entering into the cylinder, volumetric efficiency and engine friction. Baker and Lee [42] observed that at a lower speed, the reactive gas provides a longer time for the nitric oxide to form and this resulted in higher nitric oxide concentration in the combustion chamber which resulted in higher nitric oxide emission. However nitric oxide emission was decreased with the increase of engine speed. Jindal [43] investigated the effects of the engine operating parameters like compression ratio, fuel injection pressure, injection timing and engine speed on the emission of NO_X and found that higher compression ratio, injection pressure, and speed resulted in the lower emission of NO_X for pure diesel as well as diesel blended with biodiesel. Sayin et al. [44] indicated that increase in speed could probably augment volumetric efficiency, boosting turbulence in combustion chamber hence ensure better combustion which ultimately resulted in to lower CO emission at a higher speed so considering this fact higher speed is desirable for lower CO emission.

It can be observed from literature that many studies have presented variation in design factors like; alteration of fuel, use of various blends with biodiesel, variation of compression ratio, fuel injection pressure, fuel Injection timing for improvement in performance and emission parameters while other studies have presented variation in operating parameters like cetane no, load, speed and weight of the engine. To achieve performance enhancement and emission improvement along with better mobility and convenience, one of the prominent methods is weight reduction approach with a corresponding increase in the speed which has been applied in the present investigation. The effect of higher speed has already been discussed in this literature review.

APPLICATION OF WEIGHT REDUCTION APPROACH IN FLYWHEEL

After carrying out the critical study of drawings of various parts of the engine the flywheel was selected for application of weight reduction approach. The different patterns of flywheel available with the manufacturer were studied and the proper flywheel was selected. The diagram of flywheel showing the various critical dimensions is shown in Figure 1. The detailed technical specifications of existing and modified flywheels are shown in Table 1.

From the diagram and specification table, it can be observed that for reducing the weight of flywheel the material is removed from the web thickness (t1) and rim width (W) such that the moment of inertia remained undisturbed. To compensate the said reduction, the thickness of the rim (t) is increased. Ultimately, the weight of the modified flywheel has been reduced to 9 from 18 kg. After adopting these changes modified engine is developed.

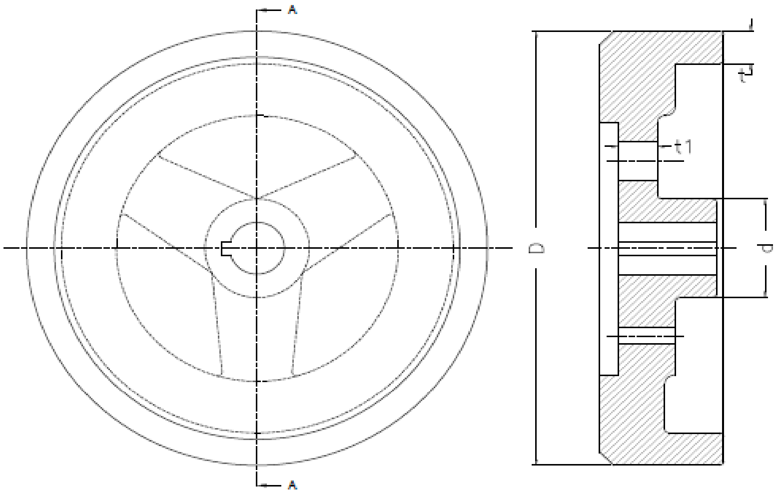

Figure 1. Flywheel

Table 1. Specifications of the flywheel.

Dimensions	Existing flywheel	Modified flywheel
Weight	18 kg	9 kg
O.D. (D)	287 mm	280 mm
Rim thickness (t)	25 mm	35 mm
Web thickness (t1)	25 mm	20 mm
Rim width (W)	70 mm	30 mm

DEVELOPMENT OF MODIFIED ENGINE

It was expected that the modified engine with lighter flywheel needs to operate at a higher speed to maintain the same rated power. For enabling the engine to run at higher speed the following additional modifications were done in the engine.

a) Reduction of bore diameter from 85 to 76 mm.
b) Reduction in stroke length from 80 to 78 mm.
c) Change in the crank diameter at flywheel end from 40 to 35 mm as per the pattern of the modified flywheel.

EXPERIMENTAL SETUP

Design of Experiment and Testing Parameters

Figure 2 shows a schematic representation of diesel engine testing facility used in the present investigations. A single cylinder vertical water cooled naturally aspirated 4-stroke constant speed DI engine of VIJAY brand model VIC-1 having compression ratio 16.5:1 and Indian Standard (IS) rating of 3.7 kW at 1800 rpm was selected for the study which is widely used in agriculture for energy applications. The detailed specifications of the existing and modified engines are shown in Table 2. The arrangement for carrying out performance and emission test simultaneously was done.

The engine was coupled to a hydraulic dynamometer with a coupler to control engine speed and load. The digital control panel having an arrangement for measurement of applied load, speed and fuel consumption digitally was attached to the hydraulic dynamometer. The inlet and outlet temperature of cooling water were measured by thermometers which are attached to corresponding passages. Digital exhaust gas pyrometer and Testo-350 exhaust gas analyzer were connected to the exhaust for measurement of exhaust gas temperature and major pollutants like CO and NO_X. Parameters observed for performance and emission analysis were power produced by the engine, engine speed (rpm), fuel consumption characteristics, exhaust temperature, CO and NO_X at different loading conditions.

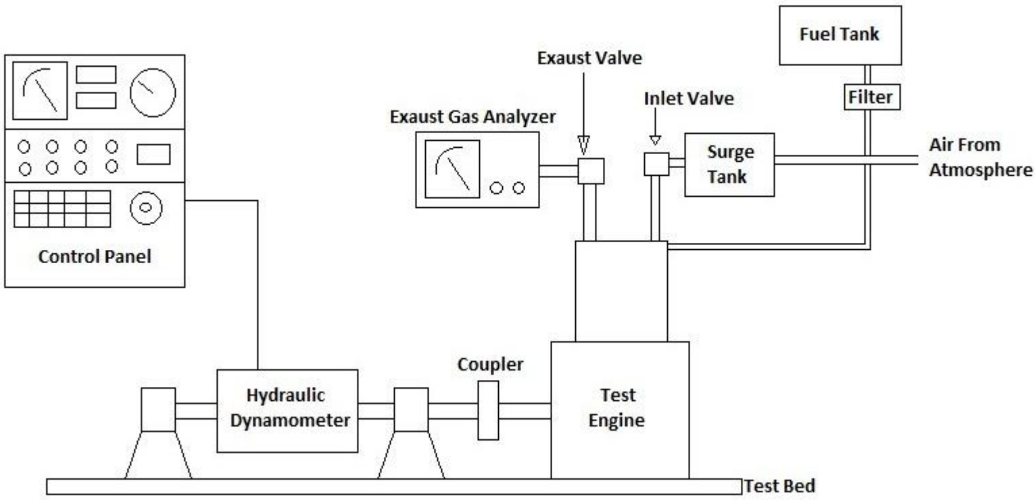

Figure 2. Schematic diagram of testing setup.

Experimental Procedure

The engine was started and after achieving steady state conditions it was loaded gradually to keep the speed within the permissible range. As per the methods mentioned in IS:11170 the loop test was conducted on both engines in which there is an increment of the load by 20 % after every half hour started ranging from no load to full load and final reading is taken at 10 % overload condition. To maintain the constant speed during the experiment while the changing load, the quantity of diesel injected was varied by speed governor. After completing the experiment at a selected speed, the speed of the engine can be altered by loosening or tightening the governor spring. Observations in respect of performance characteristics were taken at a different speed ranging from 1500 to 2200 rpm for existing engine and from 2000 to 2600 rpm for a modified engine. Results were studied for determination of the most suitable speed for each engine. The emission test was carried out on both the engines at their most suitable speed for measurement of various pollutants like CO and NO_X for verifying emission aspects. The results obtained by gas analyzer were validated at the independent laboratory by conducting stack analysis method at the full load.

Table 2. Specification of 4- stroke single cylinder water cooled engine.

Description	Existing engine	Modified engine
Rated Power (kW)	3.7	3.7
Speed variation (rpm)	1500,1800,2000 & 2200	2000,2200,2400 &2600
Bore (mm)	85	76
Stroke (mm)	80	78
Mechanical efficiency (%) (Taken from IS standard)	80	80
Altitude (m)	140 m	140 m
Nominal compression ratio	16.5:1	16.5:1
Specific gravity of fuel	0.83	0.83
Calorific value (kJ/kg)	43,900	43,900
Oil specification	Yantrol-32	Yantrol-32
Cooling	water	water

RESULTS AND DISCUSSION

Fuel Consumption

Fuel consumption gives the amount fuel consumed per hour to develop the rated power and it generally increased linearly with an increase in the percentage of load. The fuel consumption of existing engine was measured at four different speeds i.e. 1500, 1800, 2000 and 2200 rpm and for the modified engine, it was measured at four different speeds i.e. 2000, 2200, 2400 and 2600 rpm with different load condition varying from no load to overloading condition. It was observed that the existing engine gives lowest fuel consumption in entire range at 1800 rpm (Figure 3) while the modified engine gives the lowest fuel consumption ranging from no load to an overload condition at 2600 rpm. (Figure 4).

Brake Specific Fuel Consumption

Brake specific fuel consumption is the most important parameter of an engine and is defined as the consumption per unit of a power in a time unit. While measuring the brake specific fuel consumption it was observed that brake specific fuel consumption decreased in all experimental conditions with an increase in engine load, however, it again increased slightly for overloading condition.

This reduction might be the result of continuous improvement in combustion quality and efficiency with increased load. Cylinder pressure increases with higher load resulted in increased injected fuel quantity, which burned more efficiently reducing brake specific fuel consumption at higher load. Further, the results obtained from the experiment concluded that the lowest BSFC for existing engine for entire loading condition was observed at 1800 rpm (Figure 5), and for the modified engine, it was observed at 2600 rpm (Figure 6).

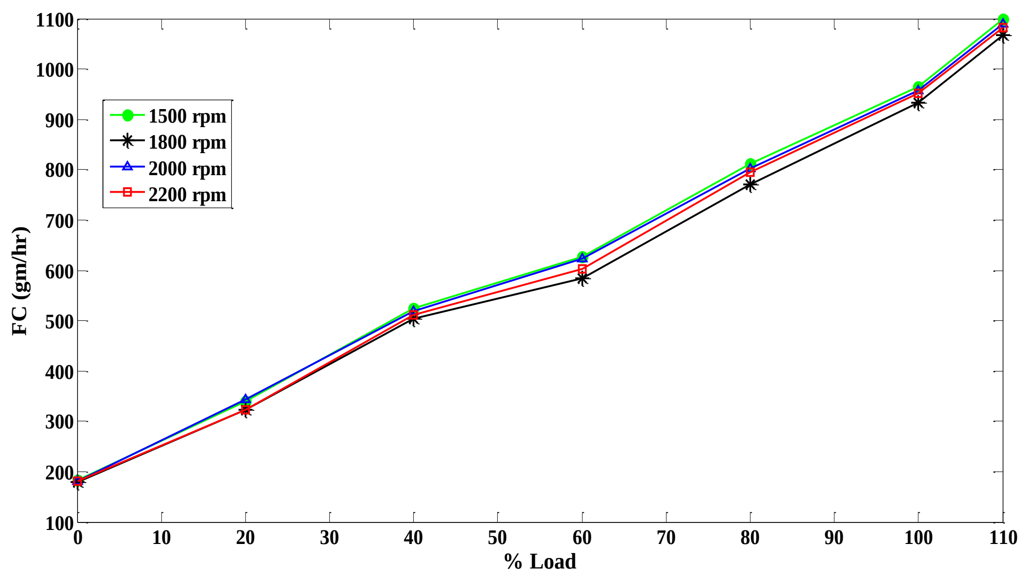

Figure 3. Fuel consumption of the existing engine.

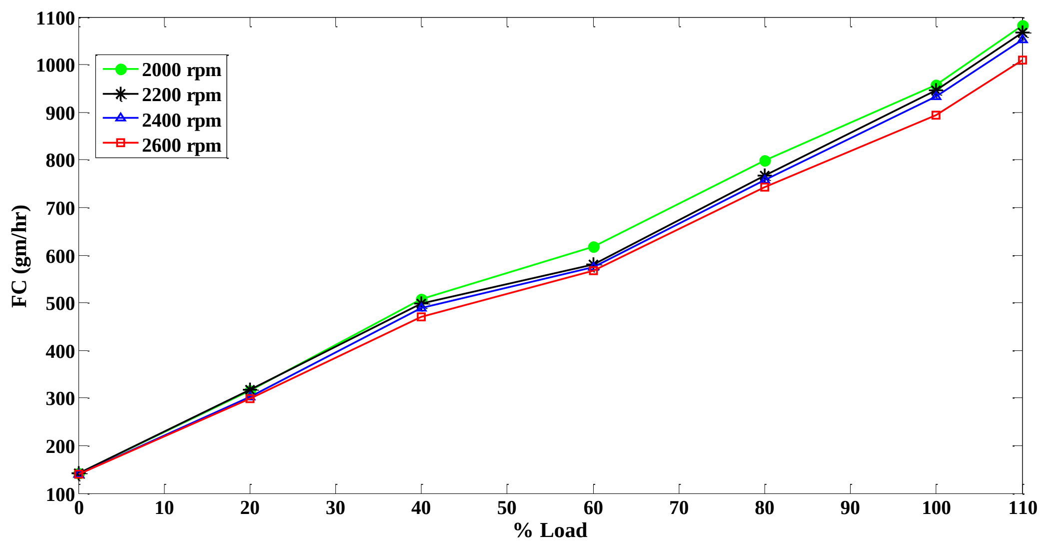

Figure 4. Fuel consumption of the modified engine.

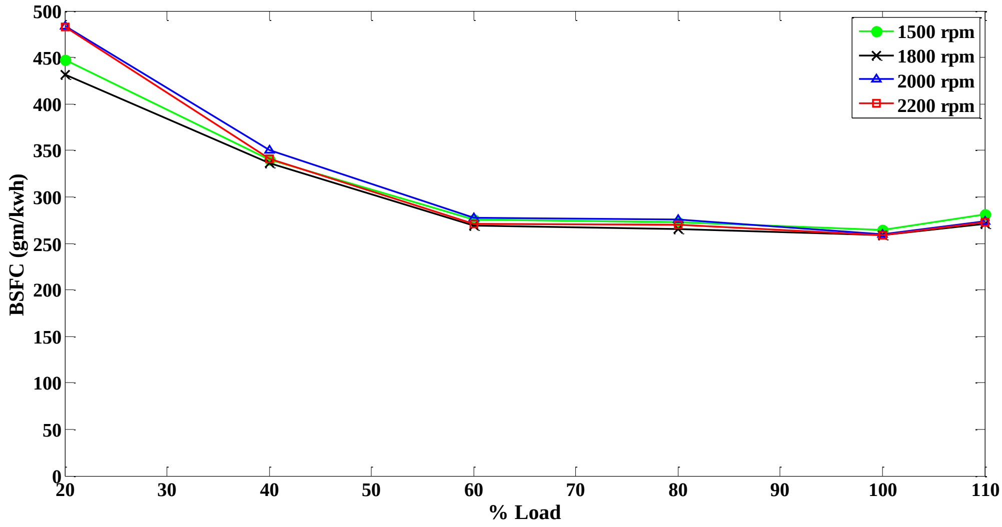

Figure 5. Brake specific fuel consumption of existing engine.

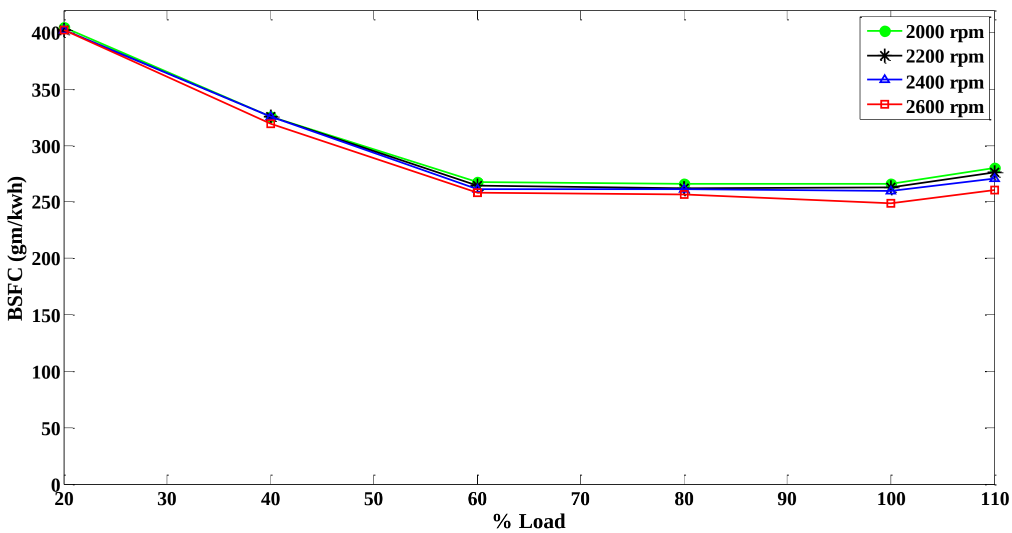

Figure 6. Brake specific fuel consumption of the modified engine.

Brake Thermal Efficiency

Brake thermal efficiency is the ratio of the output or work done by a substance in a cylinder at a given time to the input or heat energy of fuel supplied during the same time. It was observed from the results that thermal efficiency increased with the increase in the load up to full load condition which indicated that larger portion of combustion heat has been converted into work with an increase in the load. However, under overloading condition, the thermal efficiency decreased slightly because of incomplete combustion of fuel. It was also observed that the highest thermal efficiency was achieved in existing engine at 1800 rpm (Figure 7) and for the modified engine, it was achieved at 2600 rpm (Figure 8).

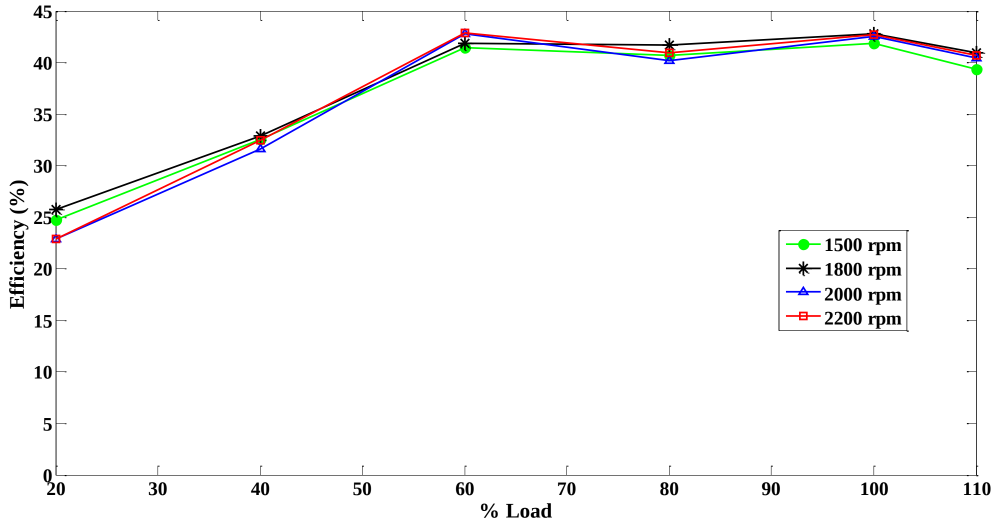

Figure 7. Brake thermal efficiency of the existing engine

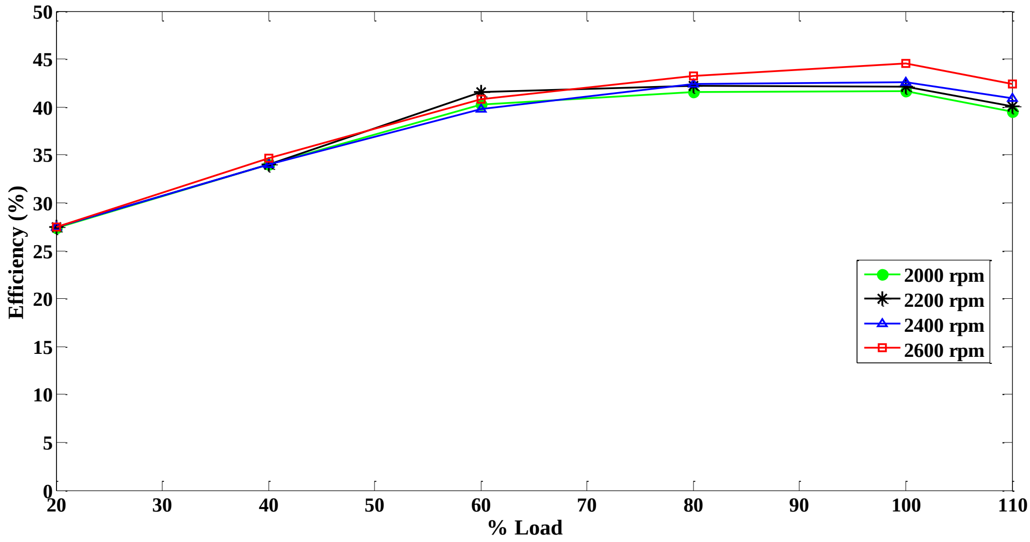

Figure 8. Brake thermal efficiency of the modified engine

Comparative Analysis of Thermal Efficiency

For conducting a comparative analysis of performance, it is desirable to find out the most suitable speed for each engine. The best values of performance parameters were achieved in existing engine at 1800 rpm and for the modified engine at 2600 rpm, therefore the most suitable speed for the existing engine and modified engine are 1800 rpm and 2600 rpm respectively. While comparing the thermal efficiency of both engines at different load condition at their most suitable speed it was observed that at almost all point from no load to overload condition the modified engine produced better thermal efficiency by approximately 2 % as compared to an existing engine (Figure 9). This performance enhancement is achieved by reducing the weight of the flywheel and corresponding increase in the speed. Higher speed probably increases volumetric efficiency, boosting turbulence in combustion chamber hence ensure better combustion which might have resulted in higher thermal efficiency in a modified engine.

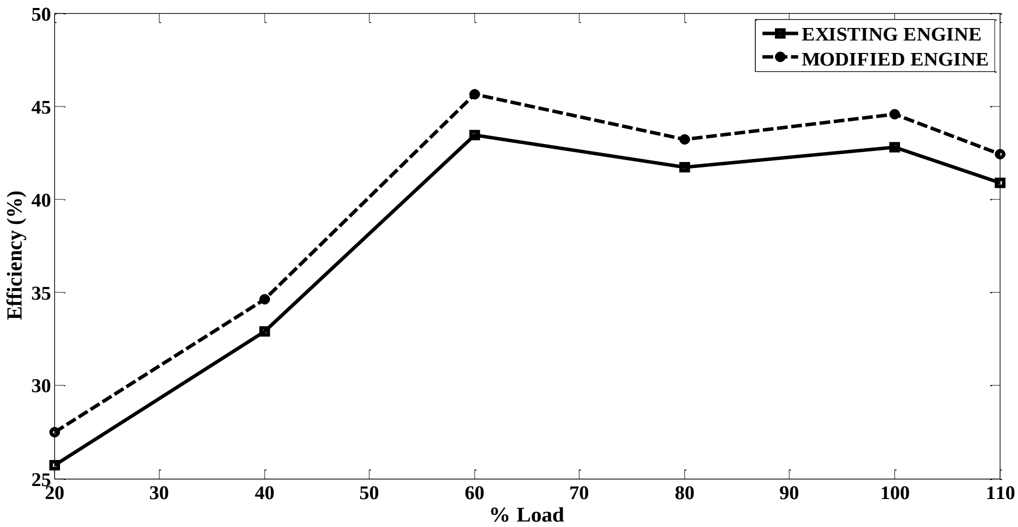

Figure 9. Thermal efficiency comparison at different loading conditions.

CO Emission

Considering the toxic nature of CO, it must be controlled. It is an intermediate product in the combustion of a hydrocarbon fuel produced due to incomplete combustion. Emission of CO depends on the air-fuel ratio relative to the stoichiometric proportion. The comparative analysis of CO emission at different loading condition is shown in Figure10. Higher CO Emission was observed with increase in load because higher load resulted in more amount of diesel fuel injected into the combustion chamber. As the amount of air remains same and fuel quantity increased, the occurrence of incomplete combustion might have resulted in higher CO emission.

It was observed that the CO emission of the modified engine was lower than existing engine in entire loading range from no load to full load. This might be due to the higher speed of the modified engine that could have probably augment volumetric efficiency, boosting turbulence in combustion chamber hence ensure better combustion which resulted into lower CO emission by approximately 4 % in the modified engine at all loading condition.

NO_X Emission

The most trouble emissions from CI engines are NO_X which contains nitric oxide (NO) and nitrogen dioxide (NO_2). The combustion temperature inside the engine cylinder and the local stoichiometric mixture are the most important factors for the formation of NO_X. The variation of NO_X emission for both engines at different load conditions is shown in Figure11. It can be observed that the NO_X emissions increased with the engine load because of higher combustion temperature at higher load.

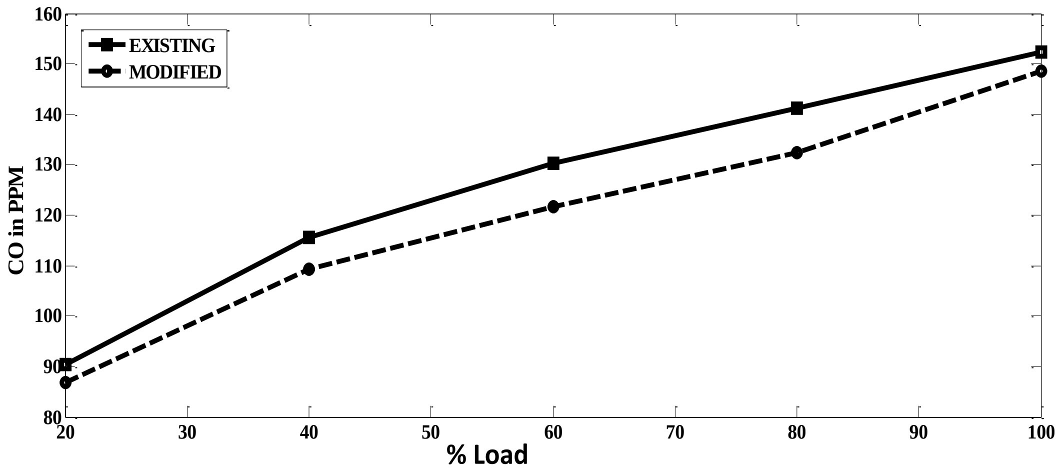

Figure 10. CO emission comparison at different loading conditions

While comparing NO_X emission of both engines at their most suitable speed it was observed that NO_X emission was lower for the modified engine at all loading condition. This might be because of lower speed of the existing engine because at lower engine speed the reactive gas provides a longer time for the nitric oxide to form and this results in higher nitric oxide concentration in the combustion chamber. Although in a modified engine with the higher speed the exhaust gas temperature increased, the NOX emission decreased, this might be due to increase in the volumetric efficiency and gas flow motion within the engine cylinder under higher engine speeds, leading faster mixture between fuel and air, and shorter ignition delay. The reaction time of each engine cycle is thereafter reduced so that the residence time of the gas temperature within the cylinder is shortened. This led to lower NO_X emissions in the modified engine by approximately 10% at full load.

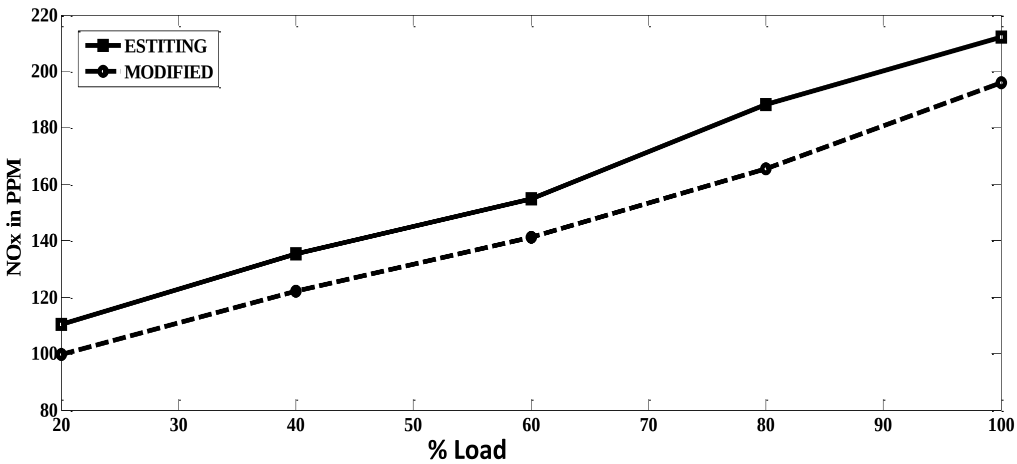

Figure 11. NO_X emission comparison at different loading conditions

CONCLUSION

The present work has tried to enhance the performance and emission aspect of a single cylinder four stroke water cooled engine using weight reduction approach in the flywheel. The findings indicated that modified engine can be used for same rated power with reduced weight and higher speed which may lead to better convenience and mobility along with improved performance and emission aspects. The salient points are as follows.

a) By following weight reduction approach, the weight of the flywheel is reduced by 9 kg (i.e. from 18 to 9 kg) without sacrificing the rated brake power.
b) By measuring the various performance parameters of both engines at a different speed, the highest brake thermal efficiency of 42.81 % at full load for existing engine is observed at 1800 rpm and for the modified engine, the highest brake thermal efficiency of 44.55 % is observed at 2600 rpm. Considering the importance of full load efficiency for engine performance the most suitable speed for existing and modified engines are 1800 and 2600 rpm respectively.
c) With the modified flywheel the engine operated successfully and performed better; BSFC was lower by 1.5 % and BTE was better by 2 % regardless of loading condition.
d) Comparing the emission aspects of both engines it can be interpreted from the graphs that modified engine gives lower emission of CO by 4 % at full load and lower emission of NO_X by 10 % as compared to existing engine at their most suitable speed.

Therefore, it can be concluded that existing engine can be replaced by a modified engine with better performance and less weight but at little higher speed

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