A Ph. D. Synopsis

Performance Investigation of High Speed Low Rating Diesel Engine

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Gujarat Technological University, Ahmedabad

Name of Student : **Hemang Jitendra Parekh**

Enrollment No. : **129990919007**

Branch : **Mechanical Engineering**

Supervisor:

Dr. Bharat. M. Ramani
Professor & Principal,
SLTIET,Rajkot
Gujarat Technological University,
Ahmedabad, Gujarat, INDIA.

Co-Supervisor:

Doctoral Progress Committee Experts:

Dr. Mitesh I Shah
Professor,
ADIT,
Vidyanagar, Gujarat, INDIA.

Dr. Rajesh Patel
Associate Professor,
PDPU,
Gandhinagar, Gujarat, INDIA.

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1. Abstract

Diesel engine is a compression ignition engine having a high compression ratio. The stationary type of diesel engine is having an application in the field of agricultural sector, small capacity generator set and irrigation purpose. The performance enhancement and emission improvement of conventional stationary diesel engine specifically used in agriculture sector will boost the overall growth and development of agricultural sector. In agricultural sector apart from performance and emission weight and cost are also key issues because the weight affects the transportation and mobility and cost affects the overall budget of small farmers.

From literature review it has been identified that the improvement in performance and emission characteristics along with reduction in weight and cost can be achieved by adopting weight reduction approach, hence it has been utilized in present case to achieve performance and emission improvement. In view of this the present work explains the solutions of ongoing problem faced by the diesel engine industry. The solution for the identified problem has been implemented and the impact of each implementation is discussed separately in detail and justified by the experimental results.

Initially, an existing engine of 3.7 kW (5 H.P) available with industry is tested for performance analysis as per the method mentioned in IS: 11170 for loop test by altering its speed. The performance parameters at various speeds are derived and compared and the rated speed was determined for selected engine on the basis of performance. Then after the engine is critically studied for weight reduction possibilities and accordingly modified to develop the lighter engine. The modified engine has been tested again following the similar method and the rated speed for the same has been derived from performance point of view. The various performance and emission parameters of both the engines at their rated speed are derived and compared. From the result it is observed that the modified engine give better results from performance and emission aspects along with better mobility and convenience at reduced cost. However, it is also identified that higher speed of modified engine leads to higher exhaust temperature which can be improved by exhaust valve replacement which may lead to further improvement in performance and emission parameters.

Therefore, exhaust valve is changed and new valve is assembled with the modified engine and performance and emission parameters are derived and compared with both previous cases. The impact of each modification on performance and emission aspect is analyzed and probable reasons for improvement in performance and emission parameters are discussed.

2. Outline of Thesis

Chapter 1 (Introduction): It includes background and motivation for present work. It also covers the area of research. Research objectives and original contribution by the thesis is also described in this Chapter-1.

Chapter 2 (Literature survey and Problem idenfication): It covers the Literature review related to present work and research gap identified after rigorous literature survey.The Research methodology employed is also discussed in details in this chapter.

Chapter 3 (Testing Methods and Regulations): It presents the testing method and regulations adopted for selected and modified engine. The detailed study of IS: 11170 and STI (Scheme of Testing and Inspection) are also covered in this chapter along with standard log sheet given for recording observations of performance and emission parameters during the test.

Chapter 4 (Development of lighter engine and Experimental set up): It presents actual implementation of weight reduction approach. Initially, the selection of proper model and method for applying weight reduction approach is done by carrying out weight analysis of various models and their critical components. As it was observed that the maximum weight was carried by flywheel in selected model of engine therefore, the detailed study of flywheel manufacutirng is done to identify different reduced weight flywheel. The additional modification which are required to adopt the reduced weight flywheel are also discussed in this chapter. To negotiate the adverse effect of higher speed on exhaust temperature the concept of valve replacement for ensuring lower exhaust temperature is also described in this chapter. The experimental set up designed and fabricated to carry out performance test, loop test and governing test as per IS:11170 along with emission test is also described in this chapter.

Chapter 5(Collection and Presentation of various experimental data): It covers the detailes of various set of experiments perfomed on both engines with observations recorded during the experimentation. Intially, the experiments are performed on existing engine to identify the performance parameters and the rated speed for existing enigne on the basis of performance parameters observed at different speeds. Then same set of experiments are performed on modified engine devloped after implementing weight reducation apprach and other necessary modifications and performance parameters along with the rated speed of the modified engine is determined from performance point of view. After that the perfomance and emission parameters of existing and modified engines are compaired at their rated speed and the effect on peromance and emisison parameters due to weight reduction approach is analyzed. Considering the higher speed of the modified engine the necessity of valve replacement is identified and the same has been done in modified engine. Then change in various peromance and emisison parameters due to valve replacement is determined and compaired with both previous cases

Chapter 6(Results and Discussion): It covers the discussion and comparison of results obtained for existing and modified engine with and without valve replacement from performance and emission aspects. The performance parameters like fuel consumption, brake specific fuel consumption and thermal efficiency along with emission parameters like carbon monoxide and nitrogen oxide are measured for all the cases and detailed comparison and analysis is presented in this chapter.

Chapter 7(Uncertainty Analysis): It covers the uncertainty calculated in each observed and derived parameter during performance and emission analysis.

Chapter 8(Conclusion): It covers the conclusion obtained from analysis of various experiments and discussion of results. The conclusion provides the guidelines and direction for the future researchers in this field by generalizing the weight reduction approach. In short conclusion is the brief outcome of the work done during entire research.

3. Brief description on the state of the art of the research topic

The various methods for achieving the performance enhancement and emission improvement are studied and analyzed.

In diesel engines, a significant research efforts[1, 2] have been conducted in direction of using various blends of bio diesel 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.[3, 4] Considerable reductions in emission of various emission elements like CO,SO_X Smoke, and particulate matter are observed while using various type of biodiesel in diesel engine as a fuel [5, 6].S. Jaichandar and K.Annamalai[7] 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 slight increase in BSFC and corresponding decrease in thermal efficiency, the considerable reduction is observed in emission parameters like CO, HC and Smoke. Neyda C et al. [8] worked on 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. Pankaj Dubey et al.[9] performed the experiment to identify the performance of combination of Jetropha biodiesel and turpentine oil in diesel engine under different loading conditions, this combination found superior from emission point of view as at full load condition, considerable emission reduction of CO, NO_X and CO_2 was observed. A.K.Azad et al.[10] 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 decrease slightly with increase in biodiesel blend; however emission decrease with increase in biodiesel blends. Further it was observed that waste oil biodiesel showed 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 [11-15]. Liang Y U et al.[16] 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.[17] studied the effect of fuel injection timing on engine performance at different speed. The results indicated that advancement in injection timing leaded to decrease in the BSFC and exhaust temperature, which lead to increase in the performance. Sathiyamoorthi R and Sankaranarayanan G.[18] 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 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.[19-21] 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[22]. Detailed study of literature review[23] emphasized that most responsible factor for CO emission is absence of excess oxygen in fuel. Some other important factors which were found responsible for the CO emission are air/fuel ratio, injection timing, engine speed, injection pressure and fuel characteristics[24]. In this connection B.S. Chauhan et al. [25] studied the effect of loading condition on NO_X and CO emission. There was increase in NO_X emission linearly with the load because of higher combustion temperature at higher load which is considered as 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 into higher CO emission therefore CO emission also increase linearly with the load. However, A A Abdelrahman[26] in his research mentioned that in diesel engine, rich mixture exists locally even if excess air is present in the combustion chamber and combustion may be poor due to lower temperature at no load condition which might be the reason of higher CO emission at no load condition.

Yackup Incingur and Duran Altiparmak [27] 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 from 46 to 54.5. However further increase in cetane no was not resulted in significant change in performance. NO_X emission was reduced by 10% with increase in cetane no from 46 to 61. S. Semin et al.[28] 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 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 than1000rpm. Some studies mentioned[29-30] that higher FIP improve fuel air mixing which resulted in faster combustion that directly influences the emission aspects. Zhang G et al.[31] observed that increase in FIP leads to improved air-fuel mixture formation which ultimately reduces smoke and CO emission. K.Kalyani Radha et al.[32] 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. A.Agarwal et al. [33] 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[34] have significant impact on engine power, efficiency and exhaust emissions. Shahadet et al[35] 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. N.Ravikumar et al.[36] analyzed the effect of compression ratio and EGR on performance, combustion and emission of 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. CR. Laguitton[37] 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.

M.Canakci et al. [38] analyzed the effect of speed on various engine parameters and claimed that speed is one of the important parameter 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. R. Baker and Chang sik lee [39] observed that at 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. S. Jindal[40] 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 was resulted in lower emission of NO_X for pure diesel as well as diesel blended with biodiesel. C.Sayin et al.[41] 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 higher speed so considering this fact higher speed is desirable for lower CO emission. Rodney J. Tabaczynski [42] studied the effect of inlet and exhaust system design on engine performance and it was observed that the by providing the whirling motion in inlet and exhaust path the overall performance of the engine can be improved. Tim G.Adams [43] conducted the experiments to investigate the effects of exhaust system design on engine performance and observed that by increasing the diameter of exhaust valve the whirling motion can be imparted in exhaust path which ensures better scavenging.

Many researchers have presented various studies for improving performance and emission parameters. However, in agricultural sector apart from performance and emission ease of transportation, convenience of mobility and cost are other key issues need to be focused; therefore weight reduction approach has been applied in present investigation to achieve improvement of performance and emission along with ease of transportation and mobility at reduced cost.

The Constraints

The modification in critical components like flywheel and exhaust valve in a particular model of diesel engine is not an easy task as it requires changes in design of these critical parts which are in operation since years. Change is always rejected at the first time for any normal working environment. As these parts are supplied by the different vendors it becomes very difficult task to convince them for modification or alteration in their regular work. However, by using practical approach all the hurdles are solved for a particular modification.

There are few constraints as listed below to be considered while implementing the corrective action for this particular problem.

1. To implement any alteration, the prior permission should be taken from top management with proper justification.
2. As the customized flywheel is not possible due to manufacturing limitations; the modified flywheel is to be selected from the patterns available with the flywheel manufacturers and corresponding modification in bore of the engine should also be done considering the availability with the manufacturers..
3. As the customized exhaust valve is not possible due to manufacturing limitations; the exhaust valve is to be selected from the dies available with the valve manufacturers.
4. It is not allowed to alter any design parameter of the product as almost all the parts of diesel engine are manufactured by interchangeability concept so modification in design of one part may disturb the design of other parts.
5. The data, drawings and test reports of the organization should not be shared anywhere without prior permission of management.
6. The confidentiality of the project work to be maintained as per the management policy.

4. Research Gap and Definition of the problem

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 compression ratio 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 corresponding increase in the speed which has been applied in present investigation. The positive and negative effect of higher speed has already been discussed in this literature review.

After identifying the research gap it has been decided to apply the weight reduction approach in some critical parts of diesel engine which can ensure material saving along with the weight reduction to ensure mobility and convenience along with cost reduction which also leads to significant improvement in performance and emission aspect.

5. Objective and Scope of work

The objectives for present work are

- To carry out the field study and survey of the engine model and to identify real issues faced by users particularly due to weight.
- To study the design and manufacturing aspects of major components of engine for the possibilities of weight reduction without affecting its performance.
- To design and fabricate experimental setup to perform performance test, loop test and governing test following standard IS: 11170 and IS: 10000 (Pt-4) as well as emission test for an existing and modified engines with reduced weight.
- To compare the performance of both engines from the output as well as emission aspect and determine the ideal speeds for both.
- To carry out economic analysis of the modified engine and study the remedies and implement them in field.

6. Original contribution by the thesis

The results of experimentation done in present work can be described with the following steps.

1. Development of experimental set up for conducting performance test and governing test as per IS: 11170:1985 and emission test simultaneously.
2. Determination of various performance parameters for existing engine at different speeds and identification of rated speed for existing engine.
3. Development of lighter modified engine using reduced weight flywheel along with reduced diameter cylinder liner and bore without altering the design of critical components of engine.
4. Determination of various performance parameters for modified engine at different speeds and identification of rated speed for modified engine.
5. Comparison of various performance and emission parameters of existing as well as modified engine at their respective rated speed.
6. Exhaust valve replacement in modified engine to ensure better scavenging in order to avoid the negative effect of higher speed of modified engine.

7. Comparison of various performance and emission parameters with and without valve replacement at a rated speed of modified engine.

7. Methodology of Research, Result / Comparison

The present work is applied research and not fundamental research. It deals with the solution of problem face by engine and pump manufacturing industry. Fundamental research is concerned with generalizations and formulation of a theory. The main aim of present work is to discover a solution for specific industrial problem.

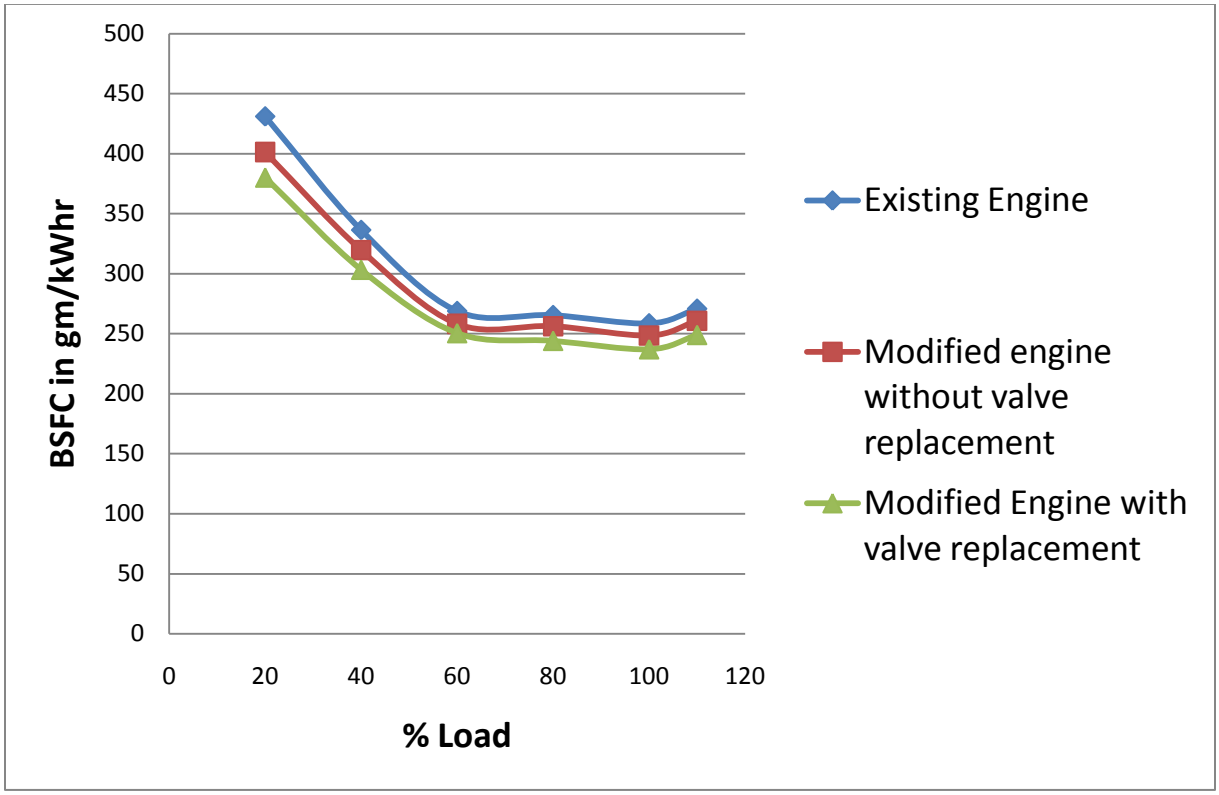
Initially, existing engine is tested for performance and emission parameters; then various critical and non –critical parts of the engine are studied for possibilities of weight reduction. Then after flywheel is selected for application of weight reduction approach and modified engine is developed by adopting reduced weight flywheel and all other modification required for adopting reduced weigh flywheel.

Again, modified engine is tested for performance and emission test following similar methods and various performance and emission parameters derived are compared with the existing one.

During experimentation it was identified that though modified engine is giving better performance and emission parameters it can be improved further by exhaust valve replacement. Therefore, exhaust valve is replaced in modified engine and performance and emission parameters with and without valve replacement are compared.

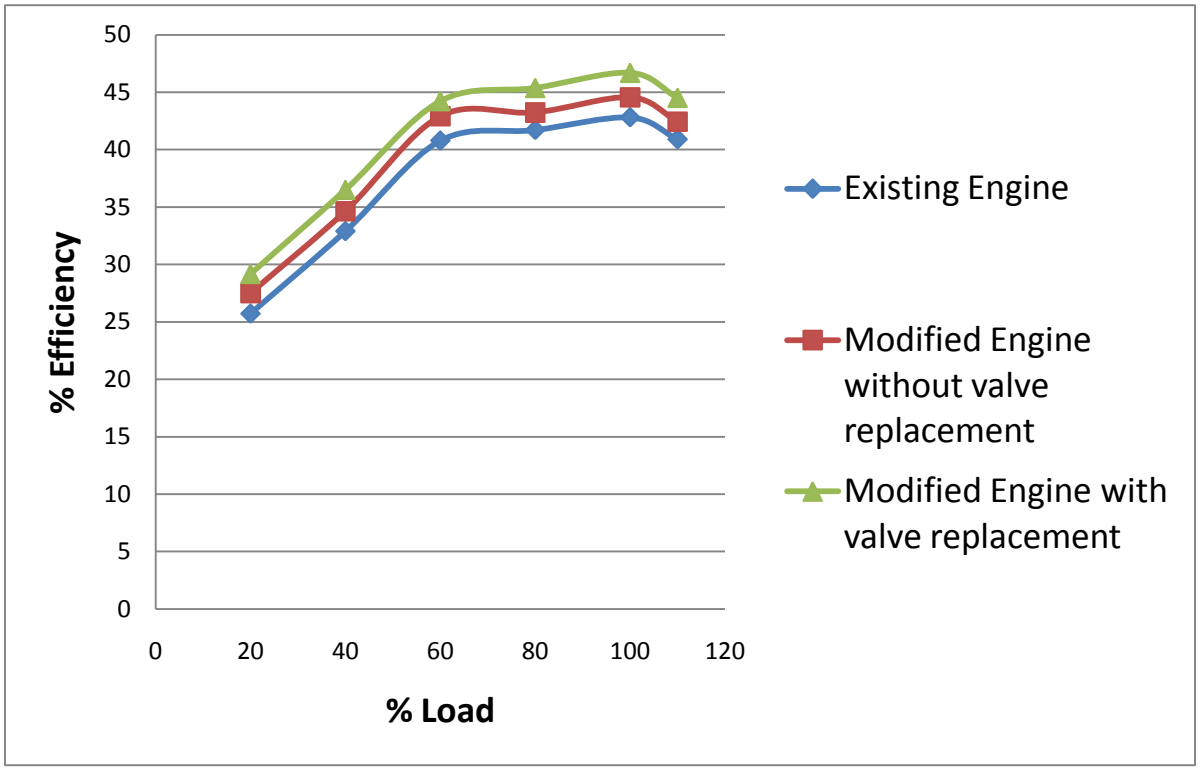
The sample graphs presents the net effect of weight reduction approach and valve replacement individually on each performance and emission parameter along with cumulative gain observed in each parameter due to these modifications.

1) BSFC (Brake Specific Fuel Consumption)



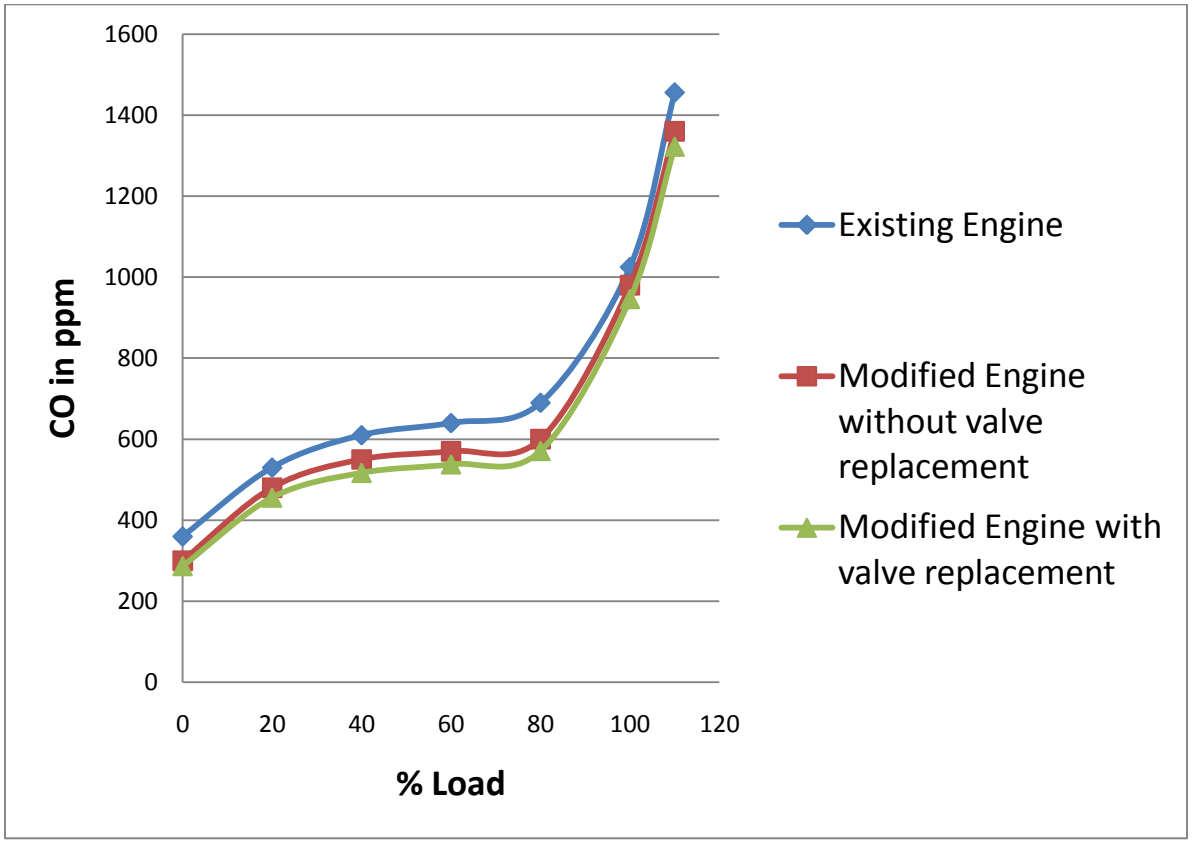
It is observed from the above graph that range of BSFC for existing engine is from 431.17gm/kWhr to 270.85gm/kWhr for existing engine, from 401.36gm/kWhr to 260.84gm/kWhr for modified engine without valve replacement and 380.21gm/kWhr to 249.06 gm/kWhr for modified engine with valve replacement. The results obtained clearly suggest improvement in performance aspect with each modification. Initially, the modified engine with lighter flywheel has been developed by adopting weight reduction approach which has resulted in 3.48 % to 7.92% lower values BSFC from no load to overload condition, specifically 3.92% lower BSFC is observed at full load condition. Then, the valve was replaced for the newly developed lighter engine, which has resulted in further reduction of BSFC by 2.94% to 5.26% from no load to overload condition, specifically 4.57% lower BSFC is observed at full load condition. From the analysis it has been observed that by both of these modifications i.e. weight reduction and the valve replacement approximately 6.82% to 11.82% reduction in BSFC is achieved which is prominent sign of improvement in performance aspect.

2) Brake Thermal Efficiency



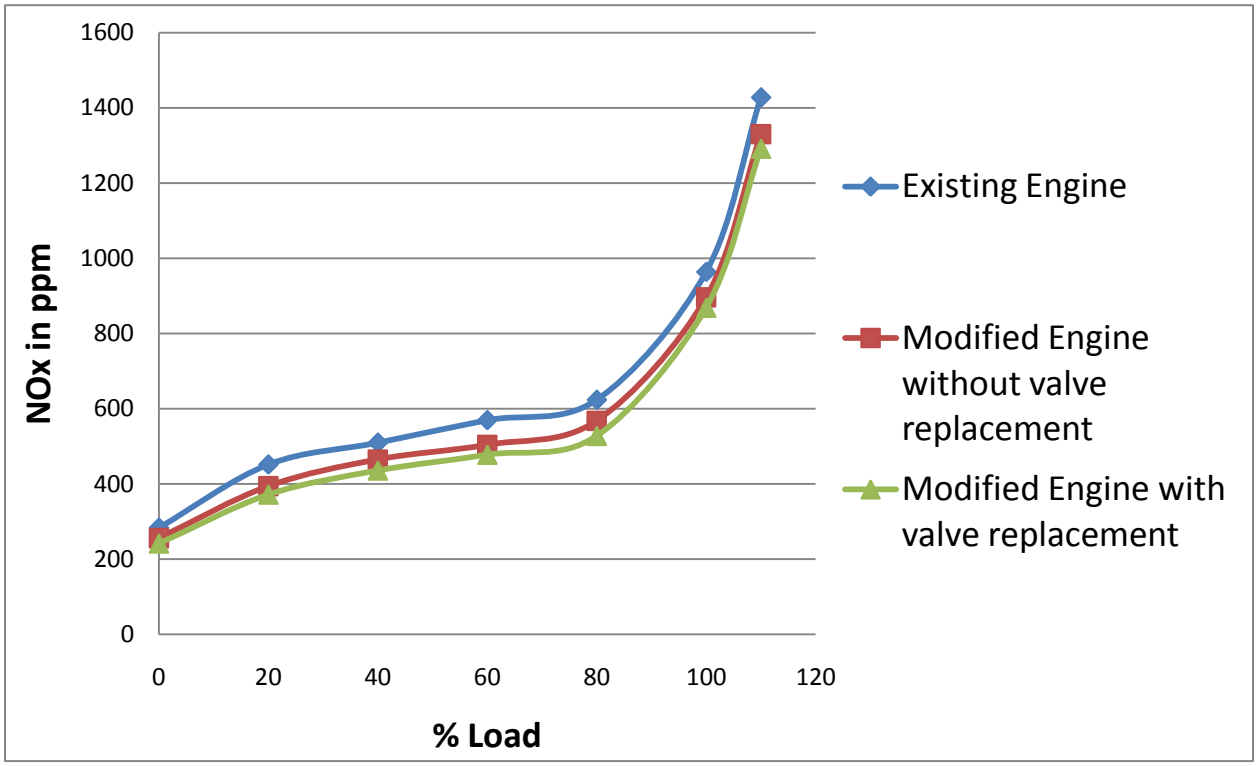
It is observed from the graph that the thermal efficiency is from 25.72% to 42.81% for existing engine, from 27.50% to 44.55% for modified engine without valve replacement and from 29.17% to 46.69% for modified engine with valve replacement. It has also been observed from the graph that the thermal efficiency can be improved by 1.52% to 2.12% by developing modified engine after adopting the weight reduction approach from no load to overload condition, specifically higher thermal efficiency by 1.74% is observed at full load condition. In addition to that the thermal efficiency can be further improved by 1.67% to 2.14% by valve replacement, specifically higher thermal efficiency by 2.14% is observed at full load condition. Ultimately, the thermal efficiency can be improved by 3.44% to 3.88% by replacing the existing engine with modified engine along with exhaust valve replacement.

3) CO emission



It is observed from the graph that CO emission is from 360 ppm to 1456 ppm for existing engine, from 300 ppm to 1360 ppm for modified engine without valve replacement and from 287ppm to 1322 ppm for modified engine with valve replacement under different loading condition. It has also been observed that the CO emission of modified engine with lighter flywheel is 4.40% to 16.66% lower than the existing engine in different loading condition, specifically 4.40% lower CO emission is observed at full load condition. Further improvement in CO emission is achieved by reducing exhaust temperature which is done by exhaust valve replacement. It has been observed that by valve replacement in modified engine CO emission can be further lowered by approximately 2.79% to 6.0%, specifically 3.47% lower CO emission is observed at full load condition. Therefore, overall improvement in CO emission is by approximately 7.70% to 20.27%. This reduction is by 20.27% at no load condition however it is reduced to 7.70% at full load condition.

4) NO_X emission



It is observed that NO_X emission is from 284 ppm to 1428 ppm for existing engine, from 256 ppm to 1330 ppm for modified engine without valve replacement and from 242 ppm to 1292 ppm for modified engine with valve replacement under different loading condition. It has also been observed that the NO_X emission by developing the reduced weight modified engine can be reduced under different loading condition by 6.86% to 12.83%, specifically 7.05% lower emission is observed at full load condition.

However, the higher exhaust gas temperature resulted from higher speed of modified engine has restricted further improvement in NO_X emission. In order to overcome this limitation the valve replacement is done which has ultimately resulted in further reduction in NO_X emission under different loading condition by 2.85% to 6.23% and especially 3.01% lower at full load condition. Hence, overall reduction in NO_X emission under different loading condition by 9.52% to 17.70%, specially 9.85% lower emission at full load condition is achieved by replacing the existing engine with modified engine along with exhaust valve replacement.

8. Achievements with respect to the objectives

The following achievements are achieved with respect to objectives set before the start of the research.

1) Field survey was carried out and problem faced by the real users due to the weight of the engine are studied and specific model for applying weight reduction approach is identified.
2) The experimental set up for carrying out performance test, governing test and emission test simultaneously is designed and fabricated as per the relevant IS standard.
3) The existing engine of selected model is tested on experimental set up for performance test altering its speed and the various performance parameters are derived at different speed and the rated speed for the same is derived from performance point of view.
4) Weight reduction approach is applied to flywheel and lighter flywheel is selected from available pattern and the same is accommodated in engine along with all other modifications required for adopting reduced weight flywheel and lighter modified engine is developed.
5) The modified engine is tested for performance test in same set up altering its speed and various performance parameters are derived at different speed and the rated speed for the same is derived from performance point of view.
6) The performance and emission parameters of both the engines are compared at their rated speed and it is observed that modified engine is better from performance and emission aspect with reduced weight. However to overcome the negative effect of higher speed on performance and emission the exhaust valve for modified enigne is replaced.
7) Performance and emission parameters of modified engine with and without valve replacement are compared and significant improvement in performance and emission parameter is observed along with better mobility and convenience at reduced cost.
8) Comparison of modified engine with existing engine from weight, cost, performance and emission point of view is carried out by replacing it in the field and feedback are studied.

9. Conclusion

The present work has attempted to enhance the performance and emission aspect of a single cylinder four stroke water cooled diesel engine using weight reduction approach. The findings indicated that modified engine can be used for same rated power with reduced weight and higher speed which will lead to better convenience and mobility at reduced cost along with improved performance and emission aspects.

1. It is observed that by following weight reduction approach, the weight of the flywheel is reduced by 9 kg i.e. from 18 kg to 9 kg and weight of cylinder liner is reduced from 7.5 kg to 6.2 kg without affecting the rated brake power. Therefore, overall weight of the modified engine is reduced by10.300 kg which is significant saving of material along with ease of transportation and convenience of mobility along with cost reduction by 20% for same rated power.
2. It is also observed while measuring the various performance parameters of both engines at different speed that the highest brake thermal efficiency of 42.81% at full load for existing engine is observed at 1800 rpm and for modified engine the highest brake thermal efficiency of 44.55% is observed at 2600 rpm. Considering the importance of full load efficiency from performance point of view the rated speed for existing and modified engines are selected as 1800 rpm and 2600 rpm respectively.
3. a) With the lighter flywheel the modified engine without valve replacement operated successfully and the effect on performance and emission parameters are discussed below;
    1) Brake Specific Fuel Consumption (BSFC) is lowered by 3.48%-7.92%, and particularly by 3.92% at full load condition.
    2) Brake thermal efficiency (BTE) is increased by 1.5%-2.1%, and particularly by 1.7% at full load condition.
    3) CO emission is lowered by 4.40%-16.66%, and particularly by 4.40% at full load condition.
    4) NO_X emission is lowered by 6.86%-12.83%, and particularly by 7.05% at full load condition.

b) With valve replacement in the modified engine the exhaust temperature has been reduced considerably and the effect of valve replacement on performance and emission parameters are observed below;

1) BSFC is lowered by 2.94%-5.26%, and particularly by 4.97% at full load condition. Considering the cumulative effect of weight reduction and valve replacement; BSFC is reduced by 6.82%-11.82% with reduction of 8.31% at full load condition.
2) BTE is increased by 1.7%-2.1%, and particularly by 2.1% at full load condition. Considering the cumulative effect of weight reduction and valve replacement; BTE is increased by 3.4%-3.9% with improvement by 3.9% at full load condition.
3) CO emission is lowered by 2.79%-6.00%, and particularly by 3.47% at full load condition. Considering the cumulative effect of weight reduction and valve replacement; CO emission is lowered by 7.70%-20.27% with improvement by 7.72% at full load condition.
4) NO_X emission is lowered by 2.85%-6.23%, and particularly by 3.01% at full load condition. Considering the cumulative effect of weight reduction and valve replacement; NO_X emission is lowered by 9.52%-17.70% with improvement by 9.85% at full load condition.

10. Copies of papers published/In process and a list of all publications from the thesis

Following papers are published at international level journals.

1. Hemang J Parekh., Bharat M Ramani, Chirag J Parekh. (2017). Impact Analysis of Various Design and Performance parameters on Engine Performance- a Review Paper. International Journal of Current Engineering and Scientific Research (UGC Approved) Volume-4 Issue-11, October 2017 (pp. 40-53).
2. Hemang J Parekh., Bharat M Ramani, Chirag J Parekh. (2018). Performance Enhancement of Internal Combustion Engine Using Weight Reduction Approach. International Journal of Automotive and Mechanical Engineering Volume-15 Issue-1 March 2018, *(pp.4962-4977).*
3. Hemang J Parekh., Bharat M Ramani, Chirag J Parekh (In Process) Performance Enhancement of Internal Combustion Engine by Exhaust Valve Modification.

11. Patents Applied

Not applied for any patent.

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