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Performance and Emission analysis of Diesel Engine with Design Modifications on Piston Crown

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Abstract

The present work aims to enhance the performance of existing diesel engine by modifying the piston design. Swirl piston is used to induce turbulence as an active enhancement technique. The engine is run at 250 bar injection pressure, 17.5 compression ratio by varying the injection timings. A stirrer is introduced at the top of the piston so as to inculcate more turbulence to incoming charge that improves fuel vaporization rate. Whirling motion is created in the combustion chamber by rotating the blades on the cavity/bowl of the reciprocating piston head. A simple link mechanism is provided to convert the oscillatory motion of connecting rod into the rotary motion of the vane. The experimental result clears that, the BSFC is reduced by 8.7 %, BTE is enhanced by 9.4 %, 11.8 % of CO emissions are controlled and NO_x emissions are controlled by 27 % is observed with the modified piston compared to normal piston at retarded injection timing.

Keywords: Diesel Engine, Piston, Turbulence, Diesel.

1. Introduction

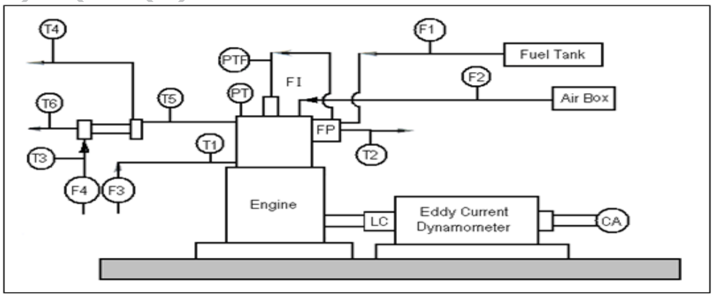
The alarming rate of depletion in world petroleum reserves has resulted two issues such as exponential rise in fuel price and conflict of global warming. The un-preceding growth in technology and accelerating population demanding more energy while the transportation sector has been occupied the second position in total energy consumption. Vigorous efforts are made to find the alternative sources of energy to replace the conventional energy sources. Among the common practical methods, combustion of diesel with direct ignition gives the notable improvement in the engine thermal efficiency. The direct ignition technique can be applied for all kinds of engines from light duty to heavy duty. In this method, mixing of fuel with air regulated in combustion chamber, thus it could able to improve the combustion efficiency [1]. A key approach this process is more turbulence is created by supplying the air in prior than regular process. Somender Singh et al. [2] modified the combustion chamber by creating grooves on it, which will in turn improve the turbulence of the charge. They created a possibility of multiple flame fronts so as to improve the combustion efficiency and reduce the heat losses. Many researchers [3-4] investigated the impact of swirling of the incoming charge on the emission and performance of the DI diesel engine. The more turbulence is induced in the charge by modifying the design of the piston head. That is a modification of combustion chamber to enhance the turbulence in the cylinder. The swirl is intensified by cutting grooves on the piston crown. J Benjacs et. al. [5] studied the performance of 1.8 L single-cylinder diesel engine with an additional attachment of the swirl rate controller. This attachment allowed variation of the mean swirl ratio. Swirl level has a significant influence on the combustion process and exhaust emissions. When the swirl ratio increased to certain level, more intense premixed combustion phase is improved. By increasing the swirl ratio, pressure and temperature of the charge are increased due to premixed and controlled combustion in the engine cylinder. Which results in the promotion of NOx formation, also reduce the soot production and increase the soot oxidation. The overall combustion duration was also shortened with reduced fuel consumption. Yang-Liang Jeng et al. [6] experimentally investigated the quality of the tumbling motion, especially for the engine with a bowl in the piston. It is observed that, a small-scale vortex will be reserved inside the bowl in the piston. In their further investigation the quality of the vertical flow in the axial plane with the generation of turbulence during the compression stroke is strongly recommended. Suzuki [7] proposed baseline modifications in piston and cylinder liners to enhance mechanical and thermal loading on vital engine parts. Hard-anodizing the piston head, reinforcing the piston head with SiC-whisker. He proposed a new process for improving the surface lubrication by introducing numerous finely distributed micro-pits. Dhinesh et al. [8-10] experimentally investigated the performance, combustion characteristics of diesel engine with and without combustion bowl modifications by using Cymbopogon Flexuosus biofuel was blended with diesel fuel in various proportions on volume basis. From his experimental results noticed that, 20% of the biofuel diesel blend gives higher efficiency and lower emissions compared to other operating fuels. Jeong-Eue Yun et al. [11] discussed the collective effect of tumble and swirl flows of charge at the inlet port. They noticed that, together with swirl and tumble motions are induced in the combustion chamber and it is difficult to separate the influence of each on combustion and also they proposed new evaluation index to characterise the in-cylinder flow. Yoshihiro Henrik W. R. Dembinski et al. [12] studied by applying different inlet port designs and valve seat making, swirl and tumble. In their study, they measure the flow of charge at the TDC by capturing the combustion images by renounced software called velocimetry. They also estimated the swirl number from the same data. They concluded that, swirling motion is progressed from compression to the combustion process, whereas tumble motion plays a vital role in the final phase of combustion. However, this tumble effect will influence the swirl motion and offset its location during combustion. Turbulence of charge plays crucial role in the combustion in IC engines. Flame speed, mixing of unburned charge is relatively poor in case of transition and low turbulent mixtures. However, homogeneous combustion can be attained by inducing turbulence either by changing the flow pattern or by changing the geometry of the combustion chamber. This leads to improve the performance of the engine. This turbulence can be increased by changing the geometry of the combustion chamber, that can be carried out either by changing the design of the cylinder head or the piston crown. At a particular operating pressure, piston speed would proportionally increase the turbulence induced in charge. However, excessive turbulence is also undesirable. The effects of turbulence can be summarized as, turbulence accelerates chemical action so that the combustion time is reduced and hence minimizes the tendency to detonate. Even though, the turbulence gives uniform combustion, higher turbulence may leads to flame extinguish. In the present work experiments are conducted at constant speed at 17.5 compression ratios with and without piston modification, 250 bar injection pressure and various injection timings at four different loads levels viz., 20%, 40%, 60% and 80% of full load.

Nomenclature

CR	Compression Ratio	BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption	CO	Carbon Monoxide
HC	Hydrocarbons	NO_x	Oxides of Nitrogen
A	Advanced Injection timing	S	Standard Injection timing
R	Retard injection timing	NP	Normal Piston
SP	Swirl Piston		

2. Experimental Setup

In order to induce the turbulence in charge, piston crown in re-designed and experiments are conducted to evaluate the performance. Schematic representation of the experimental test setup is presented in Fig.1. Experiments are conducted to study the influence of swirl and tumble on the performance of diesel engine. The engine specifications are presented in Table 1. It is a computerized single cylinder, four stroke, water cooled CI engine with an eddy current dynamometer. The engine is provided with Chromium-Aluminum thermocouples to measure the jacket water inlet and outlet (T1 & T2), calorimeter water inlet and outlet (T3 & T4), exhaust gas inlet and outlet (T5 & T6) temperatures. Engine is also provided with pressure sensors, the dynamic pressure with water cooled piezo sensor, combustion gas pressure with differential pressure transducers and fuel injection pressure with differential pressure unit. Flow rate of the cooling water is measured using a Rota meter with stainless steel float. A provision is also made in the measurement of volumetric fuel flow. A built-in program in the system calculates the indicated power, brake power, thermal efficiency.



PT	Combustion Chamber Pressure Sensor	FI	Fuel Injector
PTF	Fuel Injection Pressure Sensor	FP	Fuel Pump
T1	Jacket Water Inlet Temperature	F1	Liquid fuel flow rate
T2	Jacket Water Outlet Temperature	F2	Air Flow Rate
T3	Inlet Water Temperature at Calorimeter	F3	Jacket water flow rate
T4	Outlet Water Temperature at Calorimeter	F4	Calorimeter water flow rate
T5	Exhaust Gas Temperature before Calorimeter		
T6	Exhaust Gas Temperature after Calorimeter	LC	Load Cell
EGC	Exhaust Gas Calorimeter	CA	Crank Angle Encoder

Fig. 1: Schematic Diagram of the Experimental Set-up.

Table 1: Engine Specifications

Sl. No.	Engine parameters	Specifications
1	Engine type	TV1(Kirloskar, Four stroke)
2	Number of cylinders	Single cylinder
3	Speed	1500 rpm
4	Bore	87.5 mm
5	Stroke	110 mm
6	Swept Volume	661 cc
7	Compression Ratio	20.1:1
8	Dynamometer	Eddy Current Dynamometer
9	Type of Cooling	Water Cooling
10	Fuel Injection Pressure	250 bar
11	Fuel	Diesel

2.1.Piston Modification

Fig. 2 and Fig. 3 show the normal piston and modified piston respectively. In normal piston, piston crown is having a simple bowl shaped structure while in the modified piston is made with three blades at 120^o to each other. The same aluminum alloy is used in fabrication of chamber and 2 mm thick small strips are used to make the chamber. The modified piston assembly with the engine is as shown in Fig. 4.

Fig. 2 Normal piston

Fig. 3 modified piston

Fig. 3.6. Modified piston arrangement in cylinder

Fig. 4 Modified piston arrangement in cylinder

2.2. INDUS model PEA-205 five gas analyzer

Emission analysis is carried out by using INDUS model PEA-205 five gas analyzer is as shown in Fig.5. It has a provision for monitoring 5 gases of CO, CO_2, HC, O_2 and NOx from the engine exhaust. It is made such that it meets the OIML Class-I specifications. CO, CO_2 and HC (Hydrocarbon residue) are measured by NDIR technology and O_2 and NOx are measured by electrochemical sensors.

Fig. 5 INDUS model PEA-205 five gas analyzer

3. Results and Discussions

The experiments are conducted on a an engine fuelled with diesel by varying injection timing at 17.5 CR, 250 bar injection pressure, and with and without design modification on piston crown. The variation of BSFC with respect to load for modified piston and normal piston are as shown in Fig. 6. It can be noticed that the BSFC of modified piston is decreased compared to normal piston at all loads. The reason for this variation may be, more turbulance is created to the charge to promote the combustion effectiveness. From the experimental results, the BSFC of the engine decreased by 7 %, 2.8 % and 8.7 % with SP-A, SP-S and SP-R respectively compared to normal piston.

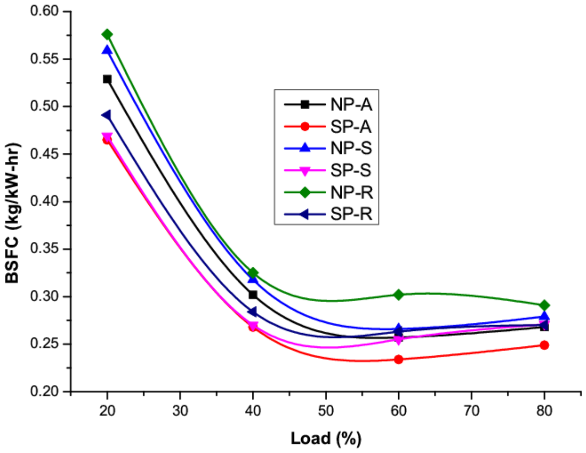


Fig. 6 Variation of BSFC with Load

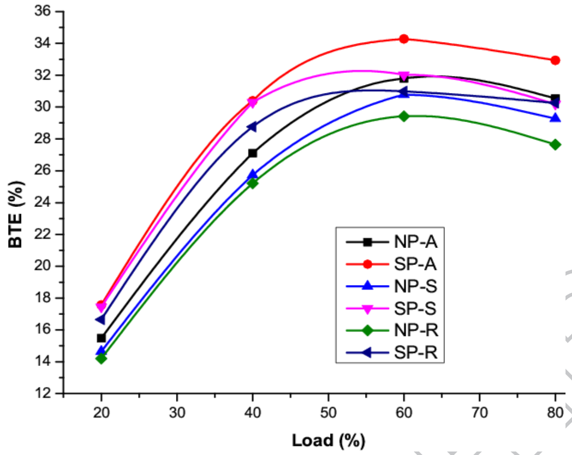


Fig. 7 Variation of BTE with Load

The influence of load on the BTE by varying the injection timing with and without modified piston design are as shown in Fig. 7. It can be observed that the brake thermal efficiency of modified piston increases with increase in load at all injection timings compared to normal piston due to homogeneous combustion by increasing the turbulence of the air. From the results the BTE is minimum 14.19 % at retard injection timing for the normal piston at 20 % load and maximum 34.29 % with advanced injection timing for the swirl piston at 60 % load. The BTE of swirl piston at 80% of load is 7.8% increased with advanced injection timing, 3.1% increased with standard injection timing and 9.4% increased with retard injection timing compared to normal piston with respect to timing. The influence of load on the ME by varying the injection timings with and without modified piston design is depicted in the Fig. 8. It can be observed that the minimum ME is 52.38 % at retard injection timing for the normal piston at 20 % load and maximum ME is 82.77% with advanced injection timing for the swirl piston at 80 % load. The ME of the engine by using the swirl piston with advanced injection timing 1.1% increse compared to swirl piston with standard injection timing and 2.08% increased compared to swirl piston with retard injection timing at 80% of load.

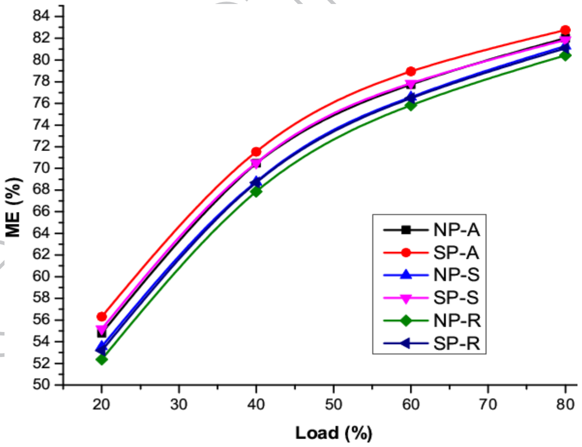


Fig. 8 Variation of ME with Load

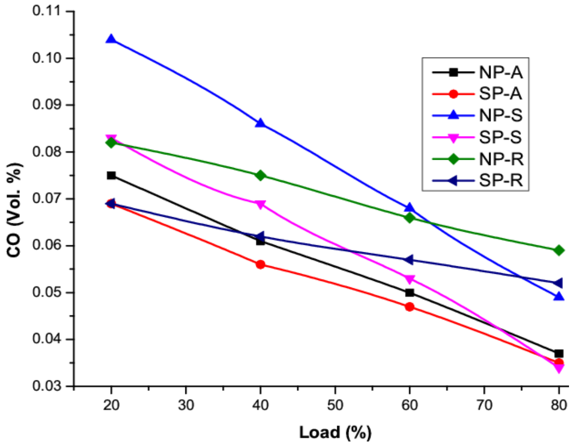


Fig. 9 Variation of CO emissions with Load

Major constituents of engine emissions are CO, O_2, CO_2, unburned HC, NO_x and particulate matter. The effect of CO emissions using modified piston is depicted in Fig. 9. From the results it is observed that, as the emission of carbon monoxide linearly decreases with load at all injection timings, but, these emissions are diminishing with swirl piston compared to normal piston. This cause may be due to homogeneous combustion by increasing the turbulence of the air. The CO emissions are minimum at standard injection timing for with modified piston at 80% of load is 0.034 Vol. % and it is maximum at standard injection timing with normal piston at 20% of load is 0.104 Vol. %. The variation of hydrocarbons with respect to load for with and without modification is depicted in Fig. 10. From the results, it can be observed that, as the emissions of hydrocarbons increases with increase in load may be due to crives formation, but, with modified piston the unburnt hydrocarbons are diminished compared to normal piston due to uniform combustion of the charge by creating turbulence to the charge at all injection timings. By using the swirl piston HC emissions are 42.85 % reduced with advanced injection timing, 36.95 % reduced with standard injection timing and 15.38 % reduced with retard injection timing when compared to normal piston at 80 % of load. The influence of load on the oxides of NO_x by varying the injection timings with and without modified piston design is depicted in the Fig. 11. NO_x emissions are increasing with uniformly increase in the peak cylinder temperature by an increase in load. The results show that NO_x is reduced with swirl piston compared to normal piston at all injection timings. Maximum NO_x emissions are decreased with swirl piston compared to normal piston at advanced injection timing. The engine exhaust NO_x emissions of the swirl piston at full load is 198 PPM for advanced injection timing, 111 PPM for standard injection timing and 154 PPM for retard injection timing. By using the swirl piston with standard injection timing 43.9 % decreased compared to advanced injection timing and 27.92% decreased compared to retard injection timing at 80% of load.

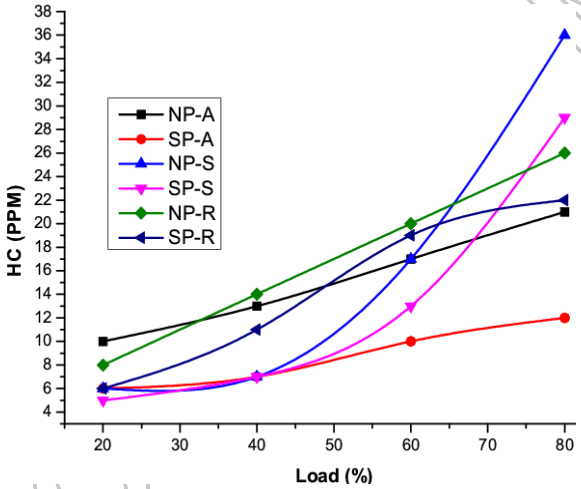


Fig. 10 Variation of HC emissions with Load

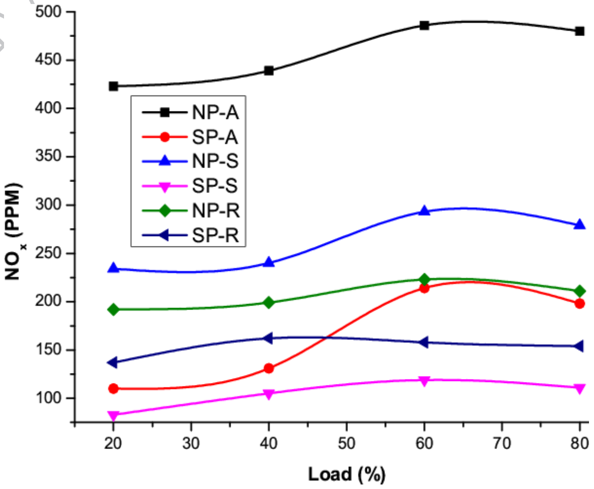


Fig. 11 Variation of NO_x emissions with Load

4. Conclusions

In order to improve the performance of an engine several active and passive alternative techniques are available. Piston modification is a one of the active technique to induce more turbulence and to minimize the emissions. In this connection, the geometry of the piston is modified by accommodating the rotating blades on piston crown to induce more turbulence by creating swirl motion to the charge.

- From the results at full load, decrement of the BSFC is 8.7 % noticed for swirl piston compared to normal piston at retarded injection timing.

- The BTE for swirl piston with 80 % load is 9.4 % increase compared to normal piston operations at retard injection timing.

- The ME for swirl piston with 80 % of load is 0.8 % increase compared to normal piston operations at retarded injection timing.

- The engine exhaust CO emissions are 11.8 % reduced at 80% load with modified piston compared to normal piston operation at retarded injection timing.

- The HC emission with the use of swirl piston 15.3 % decrement was noticed compared to normal piston even at 80% load with the retarded injection timing operations.

- The engine exhaust NO_x emissions are 27 % decreased with the use of swirl piston compared to normal piston with retarded injection timing operation.

From the above, it can be concluded that with the use of swirl piston there has been an improvement in brake thermal efficiency and decrease of brake specific fuel consumption and have a remarkable decrease in exhaust emissions of HC, NO_x. Also the results obtained for swirl piston performance are optimum at retarded injection timing compared to other injection timings.

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